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SMARTPAPER: An Interactive and User Friendly Sketching System

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Abstract

This paper describes an interactive sketching system for 3D design/modeling that diverts from the conventional menu-and-button interfaces of CAD tools. The system, dubbed SMARTPAPER, offers a unified sketching environment that supports direct sketching as well as gestured sketching with more emphasis on the former to encourage natural sketching styles. SMARTPAPER also provides a unified 2D and 3D drawing domain by allowing the user to sketch directly on a 3D model in addition to the usual 2D sketching from scratch. A natural sketching experience is offered by supporting casual sketching consisting of wiggly, discontinuous, overlapping strokes. The system is empowered by an array of seamlessly integrated 2D and 3D features such as 2D sketch cleaning, 3D reconstruction from 2D sketch, 3D transformations, sketching on 3D, and conventional 3D CSG operations like cutting and joining. The key to the success of SMARTPAPER is efficient and robust 3D reconstruction from a single freehand 2D sketch with minimal hints. We have employed and improved Lipson's optimization method, originally designed for offline reconstruction of engineering drawings, in our interactive system by leveraging additional clues obtained by interaction during sketching.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Interaction Techniques, Pen-based Interaction

1. Introduction

Designers in almost all professions use a paper and pencil to make sketches during the early stages of design. However, designing by sketches on computer has been quite difficult because of hardware usability issues. Also, the lack of 3D geometric information in sketches and the imprecision associated with them makes them very difficult to interpret algorithmically. In particular, 3D model reconstruction from a single projective sketch is a mathematically insoluble problem.

Considerable research effort has been devoted to promote design by sketches. Work has been done to support sketching schematics [GD96] and actual 3D models in architecture design. Lipson and Shpitalni [LS00, SL97, LS02, SL96, LS96] generate 3D models from 2D sketches, but their systems are non-interactive in nature. SKETCH [ZHH96] represents a fully gesture-based sketching system, which however, can be unintuitive to use if the gestures are not carefully designed and are large in number. Teddy [IMT99] employs fewer and more intuitive gestures, but it focuses on design of free-form objects. We attempt to minimize these shortcomings by providing an interactive sketching system, SMARTPAPER, that is capable of reconstructing and operating on arbitrary rigid solid geometrical shapes and is intuitive to use. SMARTPAPER draws inspiration from all the seminal work in sketch recognition mentioned above to achieve these goals. The system is implemented on a Tablet PC for a more natural sketching experience (Figure 1(a)).

We make four significant contributions through SMARTPAPER. First, SMARTPAPER presents a unified sketching environment that supports both direct and gestured sketching, with emphasis on the former. Secondly, SMARTPAPER gives more freedom to the user by supporting casual sketching styles, where several overlapping discontinuous strokes

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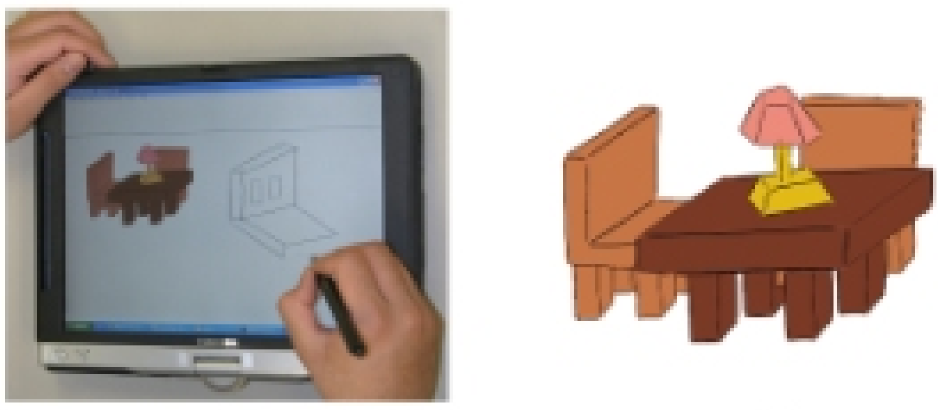


(a) (b)

Figure 1: *SMARTPAPER at a glance: (a) SMARTPAPER on a Tablet PC, (b) a scene created using SMARTPAPER.*

could be sketched. Thirdly, it allows a user to sketch directly on a 3D model in addition to making a normal 2D sketch. Fourthly, SMARTPAPER provides a feedback system that allows a user to examine the interpretation made and provide hints accordingly to improve its performance, leading to greater user satisfaction. In addition to sketch recognition, SMARTPAPER offers a compendium of Computational Solid Geometry (CSG) operations, synergistically resulting in a practical proof-of-concept system. Also, it employs non-photorealistic rendering techniques to give the reconstructed objects a sketchy look. As will become evident in section 3, from a user interface perspective, the system combines seamlessly various 2D and 3D operations such 2D sketching, sketching on 3D, 3D transformations, cutting and joining.

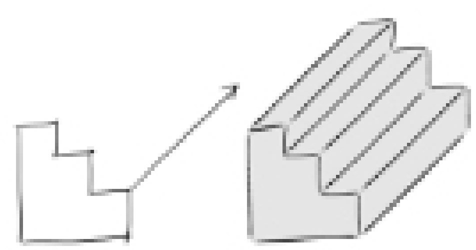
2. Previous Work

Most sketching systems focus on a particular class of entities according to their target application areas. Landay and Myers [LM95] study the application of sketch recognition in 2D user interface design. *Electronic Paper Napkin* [GD96] focusses on schematic diagrams in conceptual design, also in two dimensions. Teddy [IMT99] aims at design of 3D free-form objects using sketches. Many sketching systems [ZHH96, GD96, LS00, SL97, LS02, SL96, LS96] focus on 3D rigid objects. SMARTPAPER generates 3D models of arbitrary rigid solid objects.

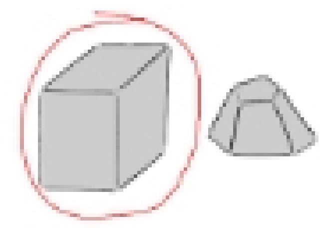
Since sketch recognition and interpretation is a mathematically insoluble problem, most sketching systems offer users some constrained drawing environment to ease reconstruction. In the system designed by Tolba *et al* [TDM01] the user iteratively sketches objects on paper, scans them into the system and aligns them on a provided "perspective grid". Igarashi *et al* [IH01] interactively generate suggestions as the user sketches. Although this may result in a greater recognition accuracy as it is based on selection instead of direct recognition after the sketch is complete, the frequent suggestions popping up on the screen while the user is sketching can be distracting. Also, these are rule-based systems and may not scale well to more general objects. Gestured interfaces like SKETCH [ZHH96] identify gestures from the input strokes and interpret them according to a fixed set of rules. The performance of these systems and their ease of use critically depend upon their ability to design intuitive and fewer gestures and accurately and faithfully recognize them respectively. Some systems [IMT99, LB90] allow direct sketching which does offer more flexibility to the user without having to learn many gestures. SMARTPAPER supports both direct and gestured sketching and reconstructs 3D objects from sketchy inputs.

Lipson *et al* [LS96] present an innovative approach to sketch reconstruction of 3D rigid objects based on optimization. The input is a scanned sketch. The sketch is processed and converted into a 2D graph. This approach then attempts to "inflate" the graph by giving suitable Z-coordinates to each vertex of the sketch, assuming that the drawing surface represents the x-y plane. These coordinates are determined by optimization based on geometric properties such as parallelism and perpendicularity of edges and faces estimated from the 2D sketch. Sometimes special properties, such as skewed symmetry, can be leveraged to make the optimization process faster [PMC03]. Later, Lipson *et al* [LS02] take a learning-based statistical approach in which correlations between 3D objects and their projections are set up and are used to identify 3D objects from arbitrary 2D projections. This approach requires considerable prior learning and works satisfactorily for mechanical engineering drawings that are more precise in nature. SMARTPAPER employs an array of modifications to Lipson's approach in [LS96] to deliver an interactive sketching system.

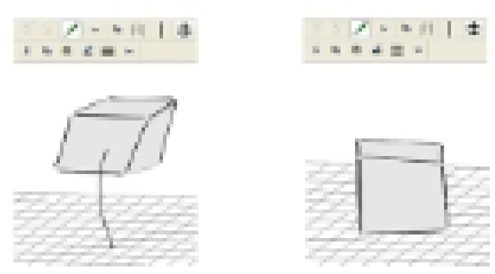
The rest of the paper is organized as follows: Section 3 summarizes a typical user experience with SMARTPAPER. Section 4 provides an overview of the system design, and Sections 5 and 6 provide details about sketch processing, representation and reconstruction. Section 7 describes the feedback system, CSG operations and provides a discussion on the NPR techniques used in SMARTPAPER. Section 8 gives the implementation details and provides a general discussion. Finally, Section 9 identifies avenues for future work.



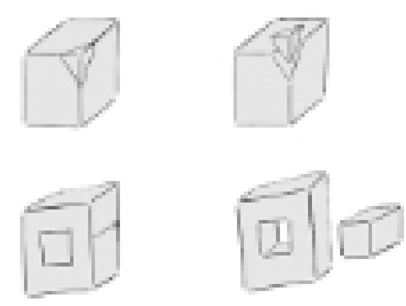
(a) Construction of an object by extrusion.



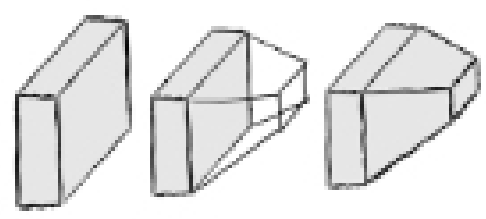
(b) Object selecting by circling.



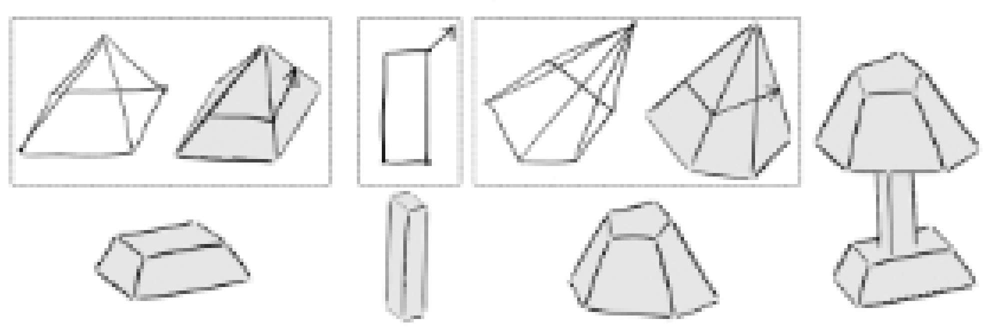
(c) Object anchoring by drawing a line between the ground and object. The line also indicates which face of the object touches the ground.



(d) Object cutting by specifying a cutting plane (top) and extrusion (bottom). Figures on the left show sketched input (triangle on top and profile and arrow on the bottom).



(e) Incremental construction of a 3D object by sketching directly on an existing 3D object.



(f) Construction of a slightly more complex object--a lamp; boxes show the steps involved in making the 3D components of the lamp: the lamp base, shaft and lamp shade, shown below them The lamp base is constructed by drawing a pyramid and then cutting it by extrusion. The shaft is constructed by drawing it by extrusion. The lamp shade is constructed by drawing a pentagonal pyramid and then cutting it by extrusion. The assembling step is not shown.

Figure 2: *Representative features of SMARTPAPER. Shaded figures are 3D objects while others are user sketches, unless otherwise specified.*