Enhanced 3D Sketch System Incorporating "Life-Size" and "Operability" Functions

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Abstract. We have been studying the use of "rich media" to support creative and intelligent human activities. Over the past ten years we have focused on the 3D space as one of "rich media" and have developed many sketch systems that support the design of 3D objects. However, long-term evaluation has revealed that they are not used by designers in the field on an ongoing basis. Even worse, they are treated as if they were merely attractions in an amusement park. The fundamental problem was the lack of an indispensable function that needs a 3D space. To overcome this problem, we previously developed a system that incorporates two new functions, "life-size" and "operability," to make a 3D sketch system that is indispensable to designers. We have now enhanced the system by extending these two functions to overcome problems identified in the previous system.

Keywords: 3D sketch, Life-size, Operability, Professional designer, Mixed reality.

1 Introduction

"Media" is an artifact that expands our creativity and intelligence. The oldest media is words and numbers. The computer is now widely used as a media.

We have been studying a wide range of creativity-centered media to ensure that the systems fully support creative and intelligent human activities. They range from those used by knowledge workers to those used by car-exterior designers [1–9]. Specifically, for over ten years, we have been developing sketch systems that support the design of 3D objects because a 3D sketch cannot be realized without the power of advanced information communication technology (ICT) [6–9]. We regard the 3D sketch made possible by the power of ICT as a drastic extension of traditional "pen and paper" media. However, long-term evaluation has revealed that our 3D sketch systems were not being used by designers in the field. Even worse, they are treated as if they were merely attractions in an amusement park. This shows that while rich media may fascinate the ordinary user, it is often ignored by the professional user. This is a serious

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problem because there are many systems that blindly utilize rich multimedia without long-term user evaluation.

Our analysis of the fundamental problems preventing 3D sketch systems from being used professionally revealed that it was the lack of an indispensable function that needs a 3D space. We thus developed a design concept inspired by “mixed reality” that makes the 3D sketch system indispensable to designers [10]. It extends the basic design concept by incorporating “life-size” and “operability” functions to better support human-computer interaction.

2 Related Work and Common Problem

Conventional research into 3D sketching can be categorized into two types. The first is generating 3D sketches from 2D sketches [16, 17]. The designer draws a 2D sketch, and then the system converts it into a 3D sketch on the basis of certain assumptions, and finally the system displays it in a 3D space. The second is drawing the 3D sketch directly in midair [11–15, 18]. The 3D lines are displayed as they are or as transformed smooth lines and converted into the model description in some systems [15, 18].

Although each type has its own strengths and has been successfully evaluated by the designers, there is a common problem—they are not utilized over the long term by professional designers for daily design tasks. They are missing something that would make them indispensable to professionals.

3 Motivation: Drawback of Previous 3D Systems

We have developed a series of 3D sketch systems [6–9] of both types. For example, our first prototype system, “Godzilla,” was designed to support creative design, specifically that of car-exterior designers [6]. The designer draws a concept image on a 2D pad (a tablet with an LCD), grasps the sketch, and holds it in midair, and the image appears as a 3D image on a 3D pad.

The short-term user test we conducted for each system showed that the user interface was promising. All the evaluators welcomed the novel interaction. However, they stopped using the 3D space after a while. For examples, with Godzilla, the users were fascinated by the display of the 3D sketch. Some were even surprised by this function. Nevertheless, sooner or later, they realized that they did not need to look at it in the 3D space as a 3D sketch. They could look at it on the 2D pad and rotate it in a similar manner. The difference was whether the image was displayed in 3D (stereoscopic) or in semi-3D on the 2D plane (perspective 2D image).

The designers eventually stopped using the 3D space because they could do their work without it. In other words, our systems did not provide designers with an indispensable function that truly needs a 3D space.

4 3D Sketch System Incorporating Life-Size and Operability Functions [10]

4.1 Indispensable Functions in 3D Space

We identified two indispensable functions that need a 3D space. The first is a life-size 3D sketch function. If a 3D sketch is life-size, the user can evaluate its size by comparing his/her body with the sketch shown in midair in front of the user. Without this life-size presentation, the user cannot evaluate the sketch on the basis of a bodily comparison, so there is no need for a 3D sketch.

The second one is a function that enables the user to "operate" the 3D sketch, that is, touch it, push it, move it, and so on. If the 3D sketch is operable, the user can evaluate the ease of use by operating it while stooping down, extending a hand, twisting his/her body, etc.

4.2 New Design Process

We developed a design process that incorporates these two functions (Fig. 1). The flow is illustrated using a copy machine design example in Fig. 2.

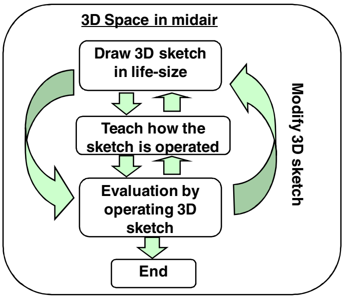

Fig. 1. New design process

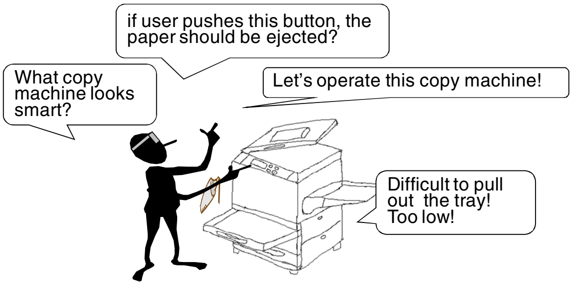

Fig. 2. Copy machine design example

The designer starts by considering the shape of the copy machine, asking him or herself, "What copy machine looks smart?" while drawing the idea life-size in mid-air.

The designer then considers the machine's operation by operating the sketch, thinking to him or herself, e.g., "This tray is difficult to pull out. It's too low. Pushing this button will eject the paper." He/She can then formulate the machine's operation rules by grasping and moving the sketch shown in 3D.

Next, the designer checks the machine's usability by operating the sketch while sitting down, stooping down, extending an arm, and so on. The designer may find, for example, that a button is hard to push because it is inconveniently located or that a tray is hard to pull out because the user has to get into an uncomfortable position. The designer can then simply erase the 3D sketch and start over.

4.3 Examples of Design Process

As shown in Fig. 3, this process can be used for various applications. It is particularly useful for control room design because it is very important to design a usable control room from the safety point of view, and it is prohibitively expensive to construct a complete mock-up. The designers would normally design it using a 3D-CAD system, which limits their ability to fully comprehend its size and operability.

In contrast, a designer using the latest version of our system would start by making a rough sketch of the control room (Fig. 3(a)). He/She would then define the operations of the levers, buttons, and warning lights (Fig. 3(b)). If any problems are found (Fig. 3(c)), they can be eliminated by redrawing the sketch (Fig. 3(d)).

Note that all this is done using hand-drawn sketches. The process can be completed in less than one hour.

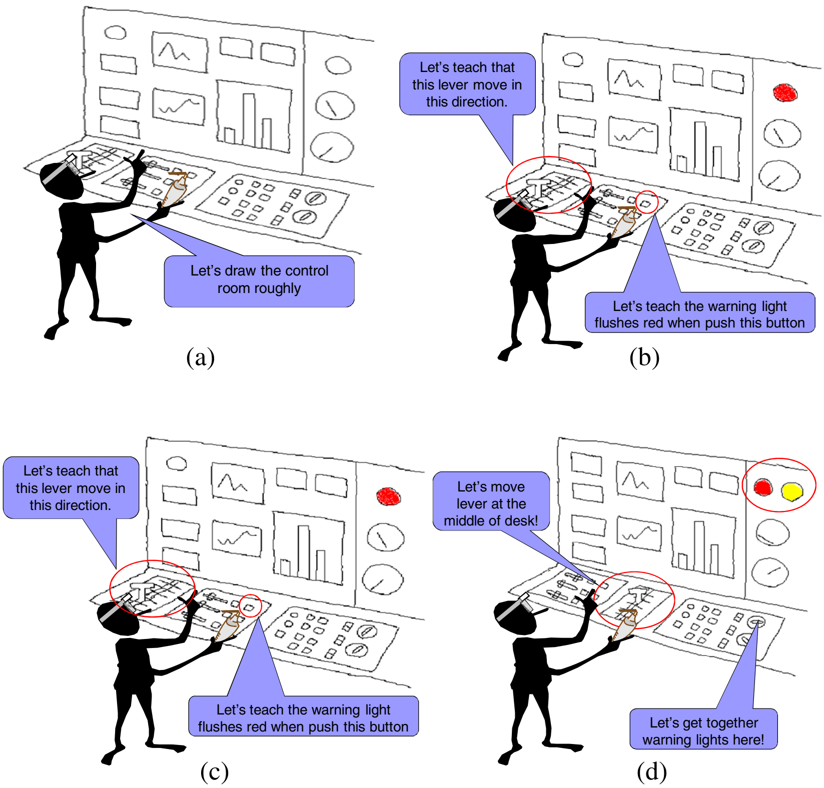

Fig. 3. Control room design example

4.4 Previous Prototype

We previously built a prototype system that includes life-size and operability functions and identified several problems.

First of all, designers complained that it was bothersome to always draw the image life size. Since the design process usually consists of several phases, they selected the design space that best matched the current design phase.

From our analysis of the design process, we had identified five attributes of the design space: dimension, quality, size, operability, and tactile. As shown in Fig. 4, “dimension” means that the designer works in a flat space, i.e., paper, or in 3D space. “Quality” means the level of design preciseness, such as rough sketch or detail. Our previous prototype supported only one combination of the attributes, the one shown by the red blocks in Fig. 4. That is why the designers complained. Although the total number of possible spaces is 32 (2^5), it is not necessary that the system support every one.

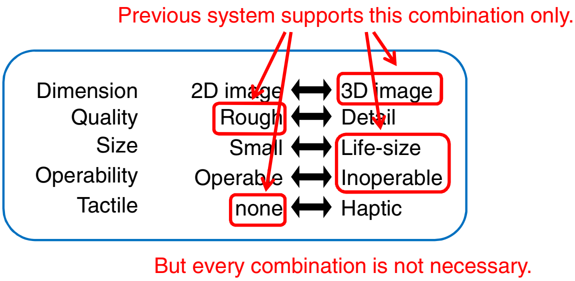

Fig. 4. Attributes of design space

The concept of “operable sketch” is attractive to designers. It is natural that the 3D sketches and the operation rules (i.e., trajectories) are displayed in single 3D space. However, the sketches are so attractive that confusion can arise between two types of sketches, as illustrated in Fig. 5. Since there are many operation rules in an actual design, the 3D sketch can become complicated if it and the definition of the operations are displayed in one space. We thus needed to simplify how the appearance and operation rules are sketched.

Moreover, since the users have to sketch the appearance and the operation rules, it is very difficult to sketch in 3D space directly. We thus needed to improve how lines are drawn in 3D space before simplifying how the appearance and operation rules are sketched.

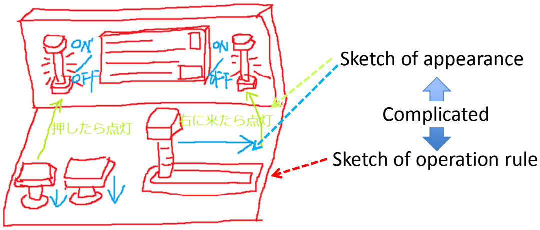

Fig. 5. Complicated sketch operation

5 Improved System

To address the designers' complaints, we developed an enhanced system that overcomes the problems we identified.

5.1 Extension of Life-Size Function

We identified the three most useful combinations of spaces and extended the design space on the basis of our findings.

(i) Design in 3D space should be both in life-size and sometimes in small size. Design in 2D should be in small size only.
(ii) Design in life-size 3D should support both operability and haptic nature. Design in small (miniature) 3D should support operability only.
(iii) Rough and detail design should be supported in all design spaces.

The first finding, that it should support 2D space and a miniature 3D space as well as a life-size 3D space, means that the system should support three spaces.

The second finding, concerning operability and tactile nature, means that the life-size 3D space needs both functions, that the miniature 3D space needs operability only, and that the 2D space needs neither of them.

The third finding means that the rough design and the detail design should be easy to traverse. The designer should be able to draw a handwritten sketch in any design space, and the sketch should be automatically converted into a detailed expression, such as font, straight line, circle, figure, and photo-realistic image , at any degree of detail and vice versa. The function should be supported in all three design spaces.

The structure of the three design spaces and the functions that each should have are illustrated in Fig. 6.

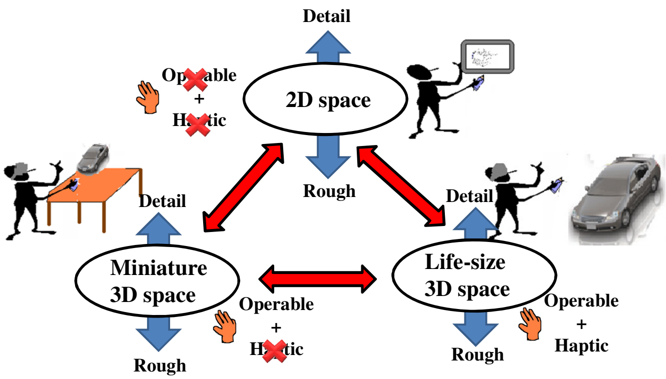

Fig. 6. Three design spaces and their supported functions

As illustrated in Fig. 7, we assigned three rough and detail design spaces: the desktop as the 2D space, the space above the desktop as the miniature 3D space, and the rest of the room as the 3D space. The corresponding experimental system is shown in Fig. 8.

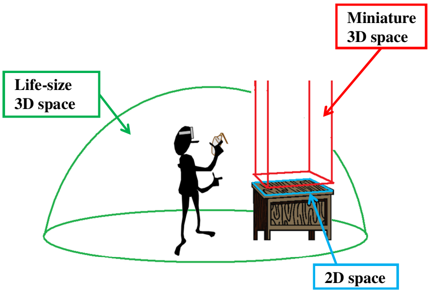

Fig. 7. Spatial assignment

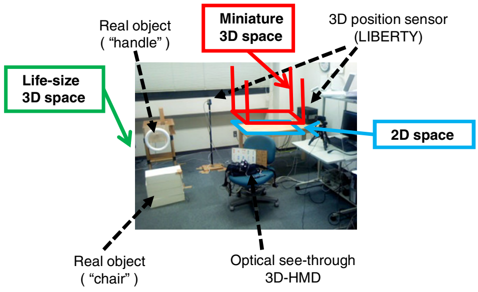

Fig. 8. Experimental system

The new extended design flow containing a life-size 3D space is shown in Fig. 9. Note that the traverse between the rough design and the detail design is controlled by moving the pen "up and down." The degree of preciseness is controlled by adjusting the height of the pen. The designer can traverse to another design space by "throwing" the design to the target space. In the life-size 3D space, the sketch can be attached to the real object. The result is an operable and haptic object and sketch. For example, if the user turns the real object handle (shown in Fig. 8) the sketch attached to the handle rotates automatically.

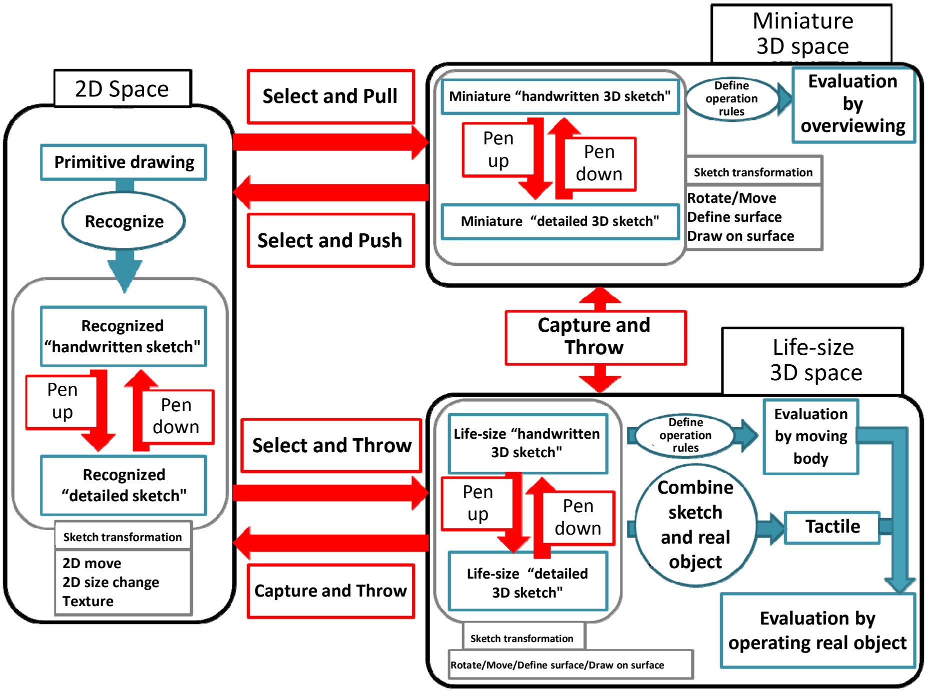

Fig. 9. New design process

5.2 Extension of Operability Function

(i) Improve how to draw lines in 3D space

There are two fundamental problems with 3D sketching: (1) it is difficult to perceive depth (distance) due to poor depth cues; (2) it is difficult to sketch on a flat plane in midair.

Our basic idea for overcoming these problems is to use a "virtual 2D plane" and an "auxiliary line." As illustrated in Fig. 10, the user freely controls the position and orientation of the virtual 2D plane by using his/her non-dominant hand. The virtual 2D plane can be seen as an extension of his/her palm. The user can easily perceive the depth of the target 3D sketch since the shadow of the target sketch is displayed on the virtual 2D plane, which continuously moves in synchronization with the hand.

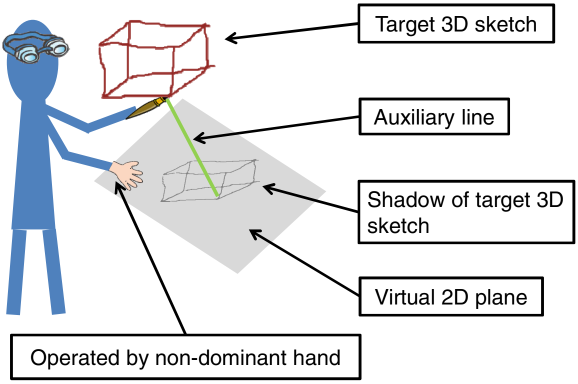

Fig. 10. "Virtual 2D plane" and "auxiliary line"

There are two types of auxiliary line. As shown in Fig. 11, a perpendicular one is used to draw a line in 3D space directly, and the shadow is displayed on the virtual 2D plane. This line connects the pen point and the shadow point. As shown in Fig. 12, an extended line enables the user to easily draw a line on a specific plane, i.e., the virtual 2D plane defined by the non-dominant hand. The virtual 2D plane improves the 3D drawing.

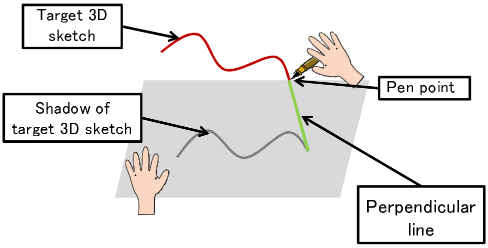

Fig. 11. Perpendicular line mode

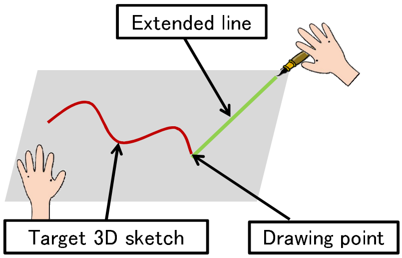

Fig. 12. Extended line mode

(ii) Revise how to sketch appearance and operation
As shown in Fig. 13, we divided the design environment into two spaces, i.e., the appearance design space and the operation design space. In the appearance design space, the user concentrates on drawing the appearance. In the operation design space, the user can easily define the operation rules by drawing iconic symbols and trajectory lines.

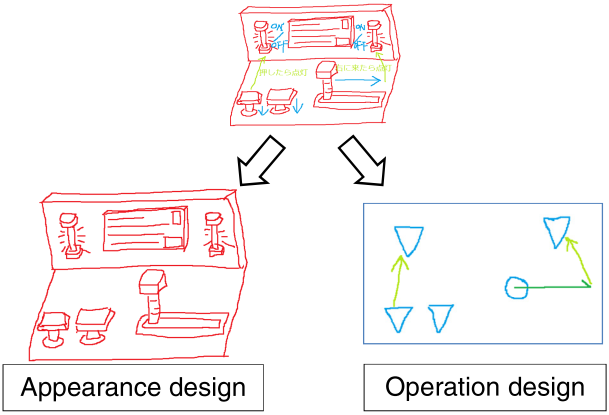

Fig. 13. Separate of appearance design and operation design

6 Summary

To address the problem of 3D sketch systems not being used by designers in the field, we implemented "life-size" and "operability" functions in a 3D sketch system. Prototype testing revealed several problems that were overcome by enhancing these two functions. The enhanced system should be a useful and effective tool for professional designers.

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