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3D Sketch System based on Life-sized and Operable Concept Enhanced by Three Design Spaces

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***Abstract*— We have been studying the use of "Rich Media" to support creative and intelligent human activities. Specifically, for over ten years we have been focusing on the 3D space as a "Rich Medium" and developed many 3D sketch systems that support the design of 3D objects. However, we found that designers in the real world do not use them. The fundamental problem is the lack of an indispensable function for using the 3D space. To overcome this problem, we have proposed "life-sized and operable" design principles. Although the new design concept made the 3D space truly useful and promoted the designer to use such a system, it revealed new problems, i.e., limited design space. In this paper, we extend this "life-sized and operable" 3D sketch system by using three design spaces, which enables the user to traverse between 2D drawing and 3D drawing spaces, between miniature and actual sizes, between rough sketching and precise design, and among still, operable, and haptic sketching.**

Keywords-3D sketch; life-size; operability

I. INTRODUCTION

"Media" are artifacts that expand our creativity and intelligence. We have been studying a wide range of creativity-centered media to ensure that systems fully support creative and intelligent human activities. They range from those used by knowledge workers to those used by car-exterior designers [1,2].

Specifically, for over ten years, we have been developing 3D sketch systems that support the design of 3D objects because a 3D sketch cannot be created without the power of advanced information communication technology (ICT). We regard a 3D sketch created using 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 their respective the fields. Even worse, they were 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 problem because there are many systems that use rich multimedia without long-term user evaluation.

II. RELATED WORK AND GOAL FOR THIS PAPER

Conventional research on 3D sketching can be categorized into two types. The first involves generating 3D sketches from 2D sketches [6-9]. The designer draws a 2D sketch, then the system converts it into a 3D sketch on the basis of certain assumptions and finally displays it in the 3D space.

The second is drawing a 3D sketch directly in midair [10-16]. The 3D lines are displayed as they are or as transformed smooth lines and converted into a model description in some systems [15]. Although tape drawing [17] uses a plane (tape) instead of a line, it can be categorized in the same class.

Although each type has its own strengths and has been successfully evaluated by designers, there is a common problem - they are not used the 3D space over the long term by professional designers for daily design tasks. They eventually stopped using the 3D space because they could do their work without it. In other words, all systems, including ours, do not provide designers with an indispensable function that truly requires the 3D space.

To overcome this problem, we have proposed "life-sized and operable" design principles [3]. Although these principles make the 3D space truly useful and promoted the designer to use such a system, it revealed new problems, i.e., limited design space.

We first briefly discuss our current "life-sized and operable" 3D sketch system as a baseline of this paper in Chap. 3 then summarize three new problems in Chap. 4. We then discuss a comparative experiment we conducted to clarify the importance of one of the problems in Chap. 5. Finally, we explain our extended 3D sketch system in detail and its evaluation in Chaps. 6, 7, and 8.

We extended our current "life-sized and operable" 3D sketch system by using three design spaces, which enables the user to traverse between 2D drawing and 3D drawing spaces, between miniature and actual sizes, between rough sketching and precise design, and among still, operable and haptic sketching.

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III. Previous System: "Life-sized and Operable" 3D Sketch System [3]

A. *Indispensable functions in 3D space*

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

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

B. *"Life-sized and Operable" design process*

We developed a design process that incorporates these two functions (Fig. 1) [3]. The flow is illustrated using a copy machine design example illustrated in Fig. 2.

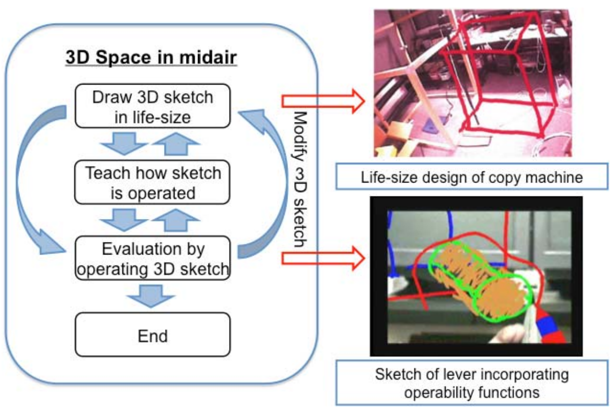

Figure 1. "Life-sized and Operable" design process.

The designer starts by considering the shape of the copy machine, asking "What copy machine looks smart?" while drawing a life-sized model in mid-air.

The designer then considers the machine's operation, thinking, e.g., "This tray moves in this direction. Pushing this button will eject the paper." She/he 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 difficult to push because it is inconveniently located or that a tray is difficult to pull out because she/he has to get into an uncomfortable position. The designer can then simply erase the 3D sketch and start over.

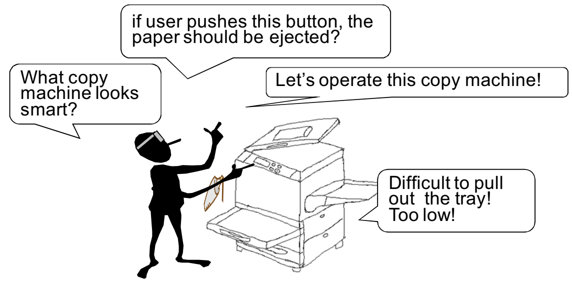

Figure 2. Copy machine design example.

IV. Problems with "Life-sized and Operable" 3D Sketch System

The "live-seized and operable" design principles, mentioned in the previous chapter, make the 3D space truly useful and promoted the designer to use such a system. However, we found that designers often complained that it was bothersome to always draw the image life sized. Since the design process usually consists of several phases, designers select the design space that best matches the current design phase. We categorized the problems they pointed out into the following three general problems.

A. *Problem 1: Support single design space only*

The current system supports only a single design space similar to other systems. For example, although designers use 2D and 3D spaces properly in accordance with the design process, the system supports "life-sized" 3D space only. This is applicable not to our system but also to most design systems.

B. *Problem 2: Limited interaction to sketch*

Although the current system supports operable sketching, which makes it quite unique, operability is actually limited. In other words, operability comes from visual instead of haptic information.

C. *Problem 3: No traverse between rough sketching and precise design*

The current system supports rough sketching by hand only and cannot handle precise design such as smooth lines and beautiful shape generation. The free bidirectional traverse between rough sketching and precise design was strongly desired because the 3D space has such a high expressive power that designers want to look at precise output such as photo-realistic rendering.

However, a precise display, such as photo-realistic rendering, is sometime harmful in the concept design phase because it traps the designers into experimental cognition instead of reflective cognition [4, 5].

V. Informal Comparative Experiment of Rough Sketching and Precise Design

Problem 3, summarized in the previous chapter, requires the support of both rough sketching and precise design. However, from the experimental and reflective cognitive points of view, precise design should be used carefully

[2,4,5]. Therefore, we conducted an informal comparative experiment of rough sketching and precise design.

A. Purpose and Method

The purpose of the experiment was to determine the effect of rough sketching and precise design on the design process. Several combinations of the traditional "pen and paper" (the output is rough and the user interface is also rough – Pattern A), MS paint (the output is rough but the user interface is precise (pen and menu) – Pattern B) and MS PowerPoint (the output is precise and the user interface is also precise (mouse and keyboard) – Pattern C) were used to design the appearance of a cellular phone, a chat client, and a portal page.

The settings of Patterns A, B, and C are summarized in Table 1.

TABLE I. SETTINGS OF DESIGN ACTIVITY

	For 15 Minutes of First Half	For 15 Minutes of Latter Half	Theme
Pattern A	Pen and Paper	PowerPoint	Buttons arrangement and menu screens of cellular phone for teen-ager girls
Pattern B	MS Paint	PowerPoint	Application of chat client which conveys emotion easily
Pattern C	PowerPoint	PowerPoint	Appearance of portal site, which is easy to use for old people and children

B. Results

The participant designer was a graduate student whose major was industrial design. The design process was videotaped and analyzed. The total length of the experiments was 90 minutes (30 min. x 3 patterns).

The design activities were labeled as (1) drastic modification and new drawing or (2) slight modification of figure, shape, size, and position. The former can be seen as a kind of the reflective design (deep and creative design), and (2) as experimental design (shallow and pleasant design, or fine adjustments).

More precisely, the activities of (2) were labeled as (2a) small change in figure, (2b) small change in size, and (2c) small change in position.

Examples of (1) and (2) are illustrated in Figs. 3 and 4, respectively.

Figure 5 shows the total time spent for (1) and (2). The designer spent more time on Pattern C in (2). Figure 6 shows the individual occurrence of (2a), (2b), and (2c). Note that the activities' patterns of the first half of the experiment (15 min.) were quite different. Figure 7 shows an example of the design output to evaluate its progress. The progress of Pattern A (paper and pen) was much better (both examples were at 1'20" from the beginning).

This comparative experiment was merely the first trial, but it shows that rough sketching and precise design might at least affect design activities.

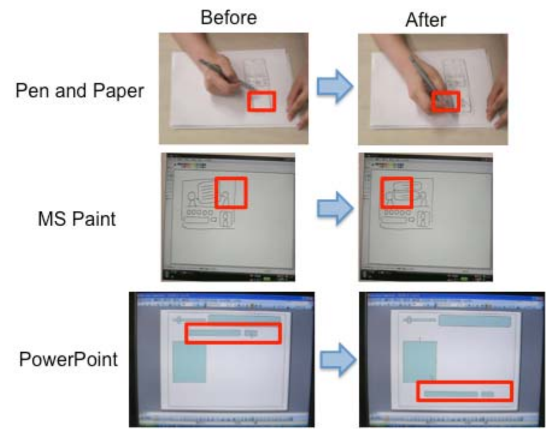

Figure 3. Example of (1) drastic modification and new drawing.

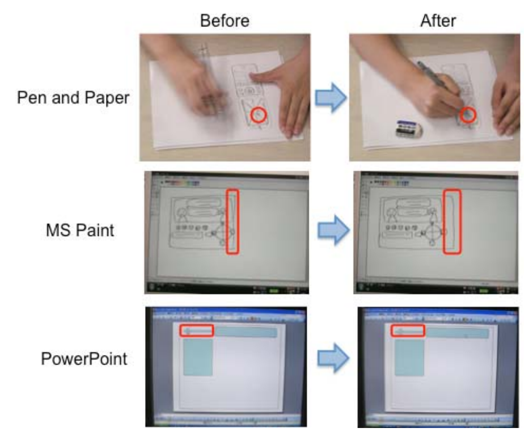

Figure 4. Example of (2) slight modification of figure, shape, size, and position.

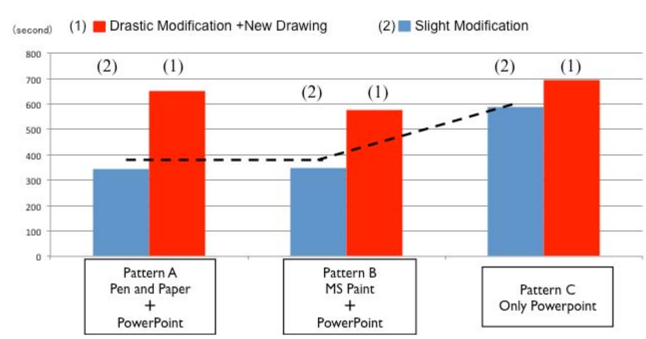

Figure 5. Time spent for creative activities and fine adjustments.

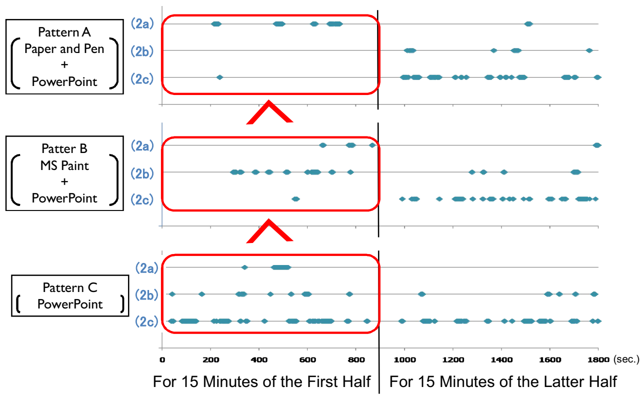

Figure 6. Appearance of slight modification in initial stage.

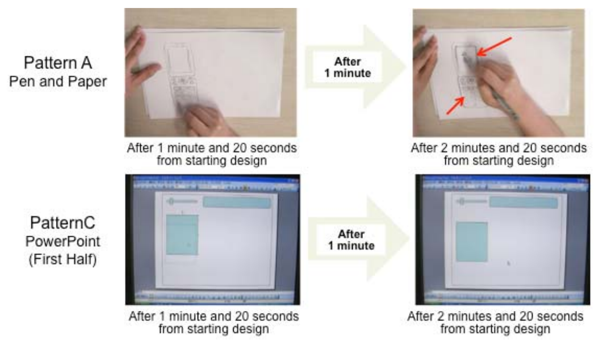

Figure 7. Design progress (at 1'20").

VI. Approaches for New 3D Sketch Environment

A. *Analysis on Design Space*

The three problems pointed out in Chap. 4 can be regarded as requirements for the design environment. It is well known that since the design process usually consists of several phases (from idea to product, as shown in Fig. 8), designers select the proper design environment that best matches the current design phase.

We identified five attributes of the design space: dimension, quality, size, operability, and tactility. As shown in Fig. 8, "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 sketching or detailed design. Our previous prototype supported only one combination of the attributes, the ones bordered with red blocks in Fig. 8. This is why designers complained. Although the total number of possible spaces is 32 (2^5), it is not necessary for the system to support every one of them.

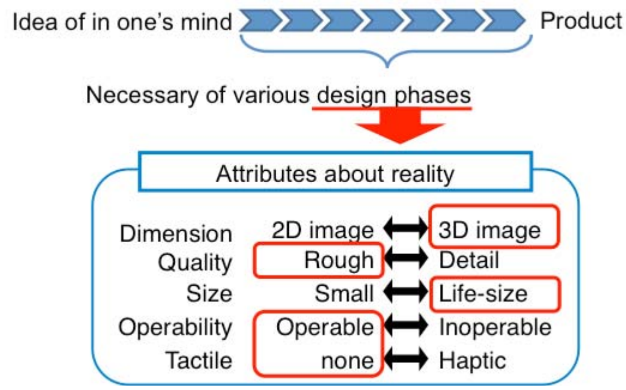

Figure 8. Attributes of design space.

B. *New architecture enhanced by three design spaces*

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

(i) Design in the 3D space should be both life-sized and sometimes small. Design in the 2D space should be small only.

(ii) Designing in life-sized 3D space should support both operability and haptic information. Designing in the miniature 3D space should support operability only.

(iii) Rough sketching and precise design should be supported in all design spaces.

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

The second finding, concerning operability and tactility, means that the life-sized 3D space requires both, the miniature 3D space requires operability only, and the 2D space requires neither.

The third finding means that rough sketching and precise design should be easy to traverse. The designer should be able to hand draw a sketch in any design space, and the sketch should be automatically converted into a precise design, such as font, straight line, circle, figure, and photo-realistic image, at any degree of detail and vice versa. This 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. 9.

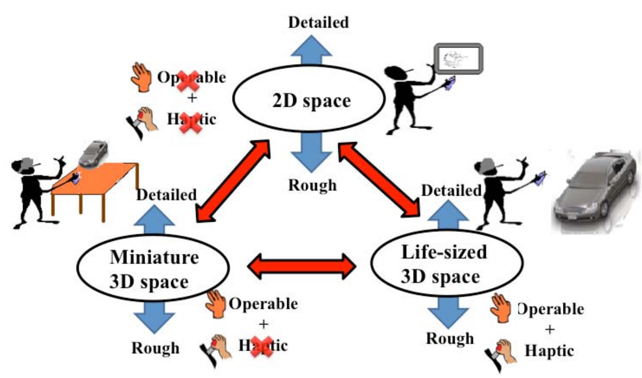

Figure 9. Three design spaces and their supported functions.

VII. Prototype System

A. Design flow

The new extended design flow is shown in Fig. 10. The design flow combines three design spaces, i.e., 2D (left box), miniature 3D (upper right box), and life-sized 3D (lower right box).

Although each space has its own functions, user interaction is consistently designed. For example, note that the traverse between rough sketching and precise design is controlled by moving the pen "up and down." The degree of preciseness is controlled by adjusting the height of the pen. This is a common interaction.

The designer can easily traverse to another design space in an intuitive manner. For example, the user "throws" the design in the miniature 3D space towards the life-sized 3D space, and the size of the design is changed and appears in life size.

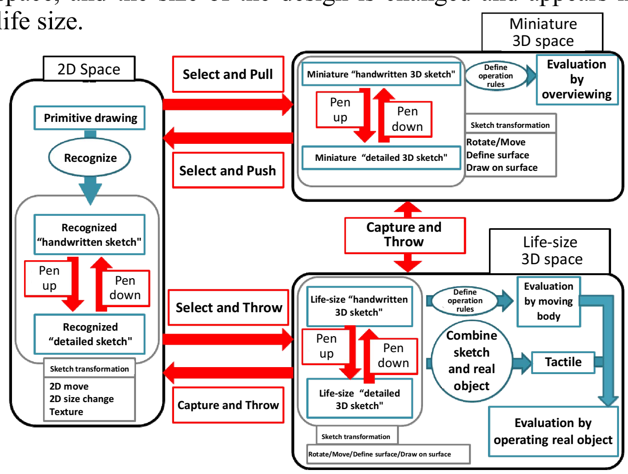

Figure 10. New design process.

B. Overview of current system

We have developed a prototype system. Figure 11 shows three design spaces. The surface of the desktop is the 2D space, the area above the desktop is the miniature 3D space, and the space beside the desk is the life-sized 3D space.

Usually a designer draws a 2D sketch on the desk top surface, then "pulls" the design above the desktop to see it in the miniature 3D space and teach the sketch how to react against the user's operation, finally he/she "throws" the design towards the side of the desk to see it in life-size and check operability.

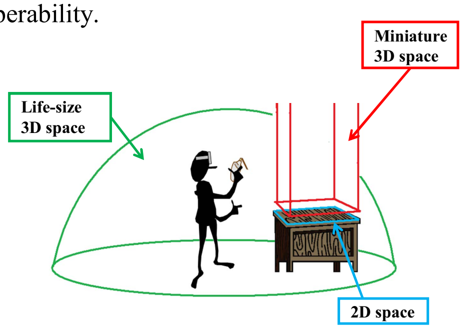

Figure 11. Spatial assignment.

The main functions are as follows:
(i) Drawing 3D space
(ii) Selecting 3D drawing
(iii) Teaching the operation rule of 3D sketch
(iv) Generating surface and drawing on the surface
(v) Transforming between 2D and 3D sketches
(vi) Traversing among three design spaces
(vii) Automatically transformation between rough sketching and precise design
(viii) Connecting between the real object and sketch for haptic interaction

Figure 12 shows the experimental environment for designing the interior of a car. The designer turns the actual object handle (shown in Fig. 12), then the sketch attached to the handle rotates automatically.

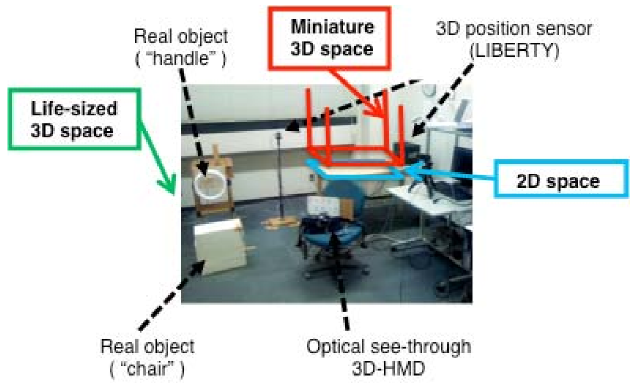

Figure 12. Experimental environment.

VIII. Evaluation by Professional Designers

A. Method

We conducted a preliminary evaluation to determine the effectiveness of our system. The participants were two professional designers. They first were asked to use the prototype system until they became familiar with it. It took about three hours each due to the many functions. They then were given the design theme and asked to design freely. The design process was videotaped and analyzed.

B. Results

Figure 13 shows the number of traverses among three design spaces. They frequently traversed among three design spaces.

However, there was no traverse inbound to the 2D space, although all other traverses were observed. This is probably due to the insufficient functions of the 2D space. In the 2D space, the designer cannot teach the operation rule and has a limited number of methods to modify the drawing, although the 3D space has full functionality. Therefore, the designer might simply draw an overview only in the 2D space and pull it into the 3D space.

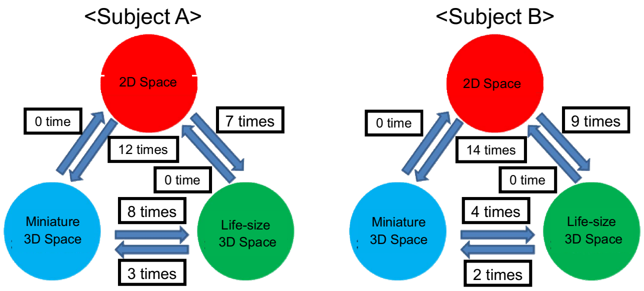

Figure 13. Experimental system.

Figure 15 shows the total time the designers spent for each design space. They used all three spaces and spent much time in the 2D, miniature 3D, and life-sized 3D spaces successively.

We believe that the observed order (2D > miniature 3D > life-sized 3D) is quite sound for the early design phrase because the designers preferred pen and paper for idea generation and did not want to spend time on checking operability. In the latter design phase, operability might be more important; therefore, the time spent in the life-sized 3D space might increase.

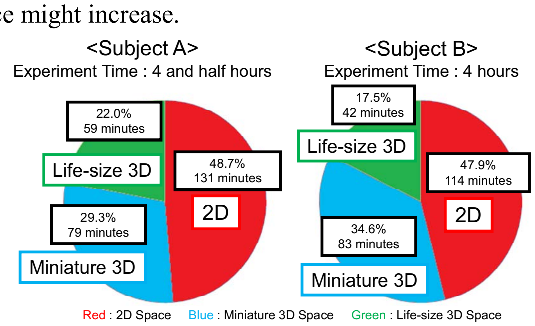

Figure 14. Percentage operating time for each design space.

IX. CONCLUSION

Our basic motivation comes from the fact there are many design support systems that use the 3D space, but professional designers do not use it. They eventually stopped using the 3D space because they could do their work without it.

Although we have developed a "life-sized and operable" 3D sketch system to overcome this problem, new problems were revealed, i.e., limited design space.

We extended our current "life-sized and operable" 3D sketch system by using three design spaces, which enables the user to traverse between 2D drawing and 3D drawing spaces, between miniature and actual sizes, between rough sketching and precise design, and among still, operable and haptic sketching.

The results of the preliminary evaluation by two professional designers are promising. We are now building a stable system for application to real design problems.

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