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Design Procedure on a Newly Developed Paper Craft

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Abstract. Personal computers are now rapidly diffusing into public facilities as well as educational organizations and common families. To let variety of user groups handle software with ease, it is an urgent business and an essential factor to develop a digital society as well as to construct a human-friendly environment for operation. This article describes a method to effectively fabricate various formative models by means of paper craft and suggests an example of educational tools with which everybody can explore the environment to be acquainted with computer and joy of creation during enjoyment.

Key Words: Paper craft, paper folding, modelling software, gesture interface

MSC 1994: 51N05, 00A35, 68N99.

1. Introduction

It is not too much to say that Japanese culture has progressed along with its use of paper. It is obvious when we see from examples that *fusumas* and *shojis* have frequently been used for Japanese architectures and are still in use. Such paper culture has not only made use of paper in practical applications but also has created various articles of folk craft with entertaining factors. What can be regarded as a representative class of Japanese paper use is *origami* as this is familiar to people without distinction of age or sex for many years. On the other hand, paper model that are 3-dimensional have flourished for many years and "papier-mâché" and the similar processes can be regarded as its representative of this type of paper art. Such paper models are now called "paper craft" and are used as one of the teaching aids for lower classes in primary school [1]. However, common problems are:

1. It is a difficult work to deform and paste paper in succession.
2. Assembling of paper craft needs complex procedure.
3. Figures design cannot be modified.

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The authors thus devised a new assembly procedure for the paper craft and further developed software that automatically draws developed plan from design of a figure and then performs the process of working its fabrication. It is featured with followings:

1. Paper craft composed of plural polyhedrons.
2. Visualization of assembly with described guidance.
3. Function of automatically drawing figure design and developed plan of paper crafts using software.

With this procedure, we simplified assembly process of paper craft and reduced burden on the user. By using the software we have developed, users can freely design shape, pattern (texture) and others characteristics of the paper craft. This article also aims to determine the feasibility of the paper craft in the digital society by fusing traditional paper culture with the personal computer. Recently, unification of analog-like raw materials and digital environments has been attempted in many fields and it typically represented by virtual art museum [2] and digital archive [3]. The authors have aimed to introduce a newly developed approach to traditional paper craft into a computer education. Its details are mentioned below:

2. Outline of polyhedron and development plan

In general, assembly of the paper craft has adopted the procedure that multiple paper sheets are successively pasted [4]. Proposed in the present paper, however, is a system of paper craft that connects multiple polyhedrons. The individual polyhedron is simple in the shape and independent from each other. Accordingly, time necessary for assembly can be shortened and its progressive state can easily be confirmed. In comparison with assembly procedure with folding or insertion as seen in past methods, this procedure we devised can simplify the process because it connects a solid to another in succession.
Described below are methods of production and processing of these polyhedrons and also a process of automatically forming developed plan of the polyhedrons:

2.1. Producing Procedure of Polyhedrons

Polyhedrons are developed using the edit screen of the software developed. Shape of a face to be the base (front view) is designated first as shown in Fig. 1. We then sweep the shape in the direction of depth (along Z-axis here) and calculate the values of each vertex with 3D coordinates. A polyhedron containing the base and side faces are formed with this procedure as shown in Fig. 2. Besides, the number of faces formable here was set up to 14.

2.2. Processing Procedure of Polyhedrons

Formed polyhedrons can be subjected to twisting operation with respect to a side face in addition to modification of size and thickness in Z-direction. It is possible, for instance, to designate the inclination angle with respect to plane of a side face of the polyhedron. By using this approach, the structure of the polyhedron can easily be changed as shown in Fig. 3. The shape of the side face can also be altered as shown in Fig. 4 by moving each apex of the side face along the plane vector of the face.

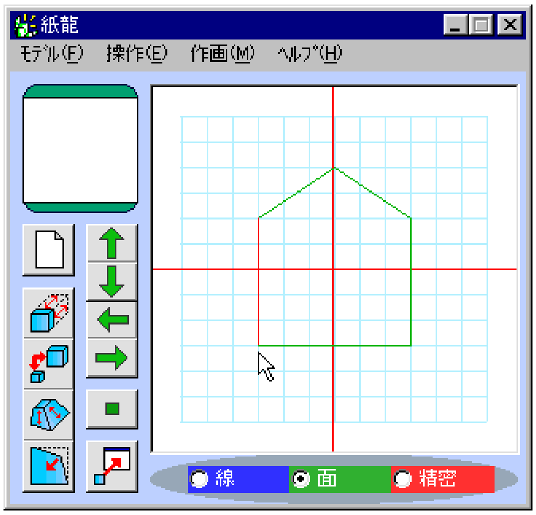


Figure 1: Designation of shape

Figure 2: An example of formation of polyhedron

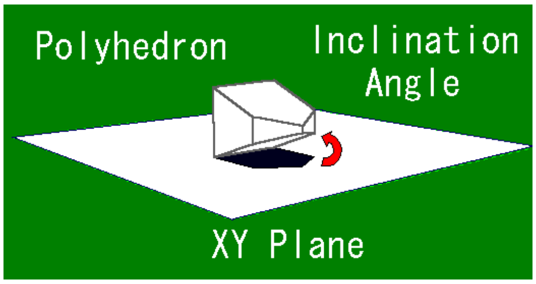


Figure 3: Processing of polyhedron

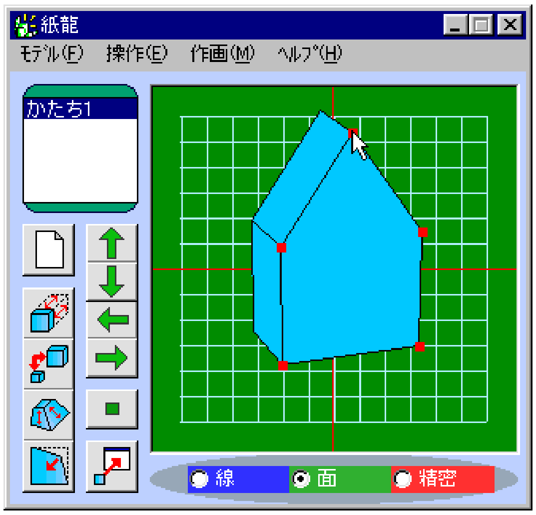


Figure 4: Deformation of polyhedron

2.3. Drawing Procedure of Developed Plan

First, a face to be the base is chosen from planes other than side faces of the polyhedron, and ordinate values of the face with respect to XY- and XZ-planes are read for every apex. Distances between each apex and angles between neighboring sides are determined from these ordinate values, and 3-dimensional ordinate values are converted into 2-dimensional ones. Based on these ordinate values, the selected face is delineated as shown in Fig. 5 by regarding it as the bottom face of the polyhedron. Next, faces neighboring the bottom face are converted into coordinates in plane successively by using similar processing. We now adjust the descriptive angles by means of the affined transformation. The above procedure allows drawing a developed plan, as shown in Fig. 6, but it goes wrong in some cases depending on figure of the polyhedron. It is necessary therefore to refer if two sides have crossed each other when drawing developed plans. If a crossing was detected, a developed plan is drawn after selecting another face as the bottom.

Figure 5: Selection of standard face and delineation

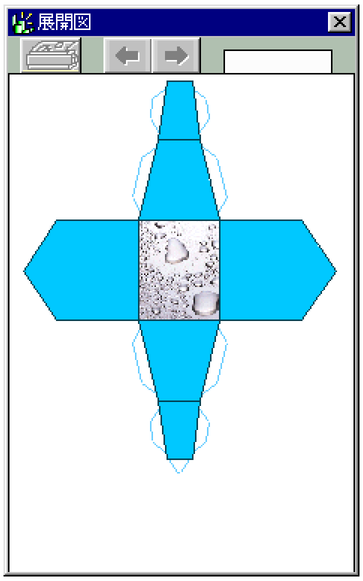


Figure 6: Developed plan

3. Design of paper craft using software

As mentioned earlier, the software described in this article is different from the software [5] in that the user simply draws development plan of polyhedrons and has laid major emphasis on design of paper craft aiming at concrete formation to the end. For this, the design of the paper craft was conducted on the model screen as shown in Fig. 7, and it was so devised that users can perform mutual connection or transfer of polyhedrons and pasting textures while confirming the final model completed in trial and error.

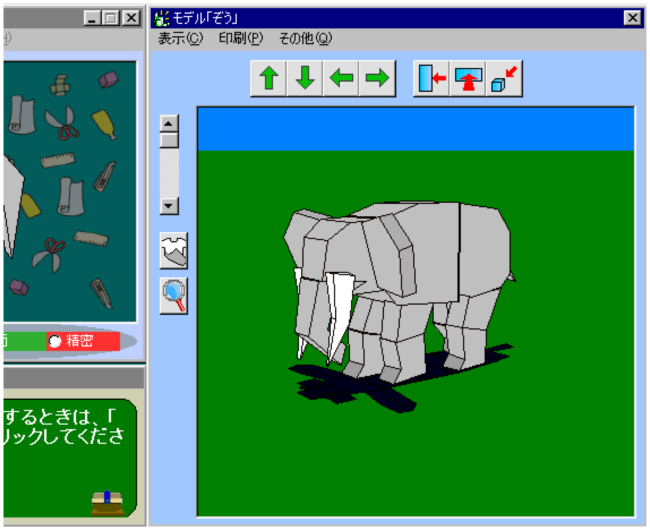
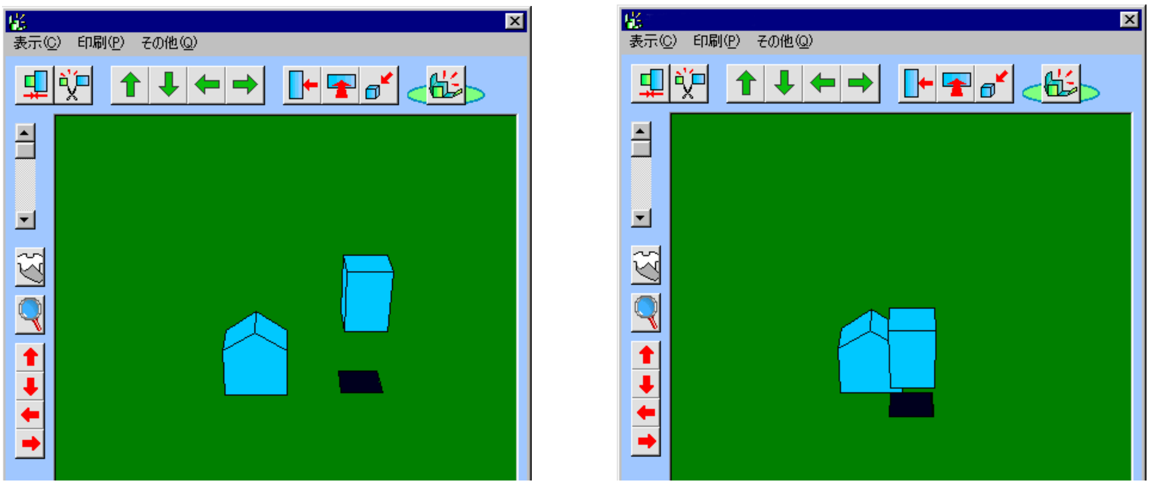


Figure 7: Model picture screen

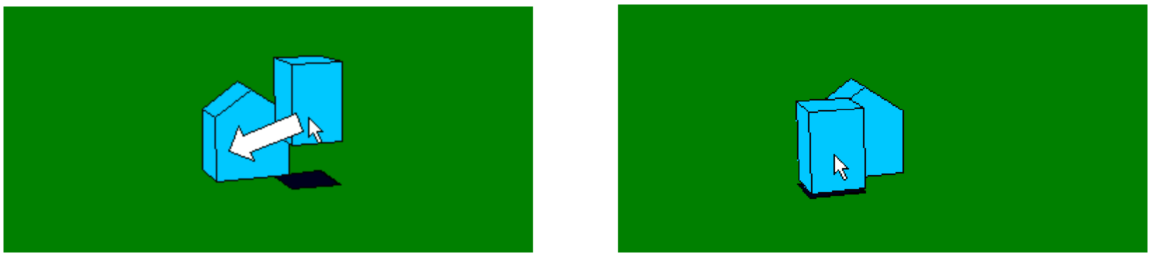
3.1. Connection and Transfer of Polyhedrons

On the model screen, the original face and partner's face to be connected are selected. This allows simple connection of polyhedrons as shown in Fig. 8. It is also possible to instantly adjust the connected position simply by dragging the connected polyhedron. This operation can be practiced in any display angle of the polyhedron. Accordingly, users are can confirm the polyhedrons in question from various angles and adjust the connected position at needed. At this time, coordinate system of the model screen is 3-dimensional though motion of the mouse is 2-dimensional. Thus, the plane vector is calculated from coordinates of each apex in the plane to convert the transfer quantity of the mouse. For instance, when the mouse is transferred to the lower left as shown in Fig. 9, movement of the mouse is converted into quantity of transfer that the plane vector is projected onto the XY-plane, and the polyhedron can be transferred in the direction along the plane.



(a) Separated (b) Connected

Figure 8: Connection of polyhedrons

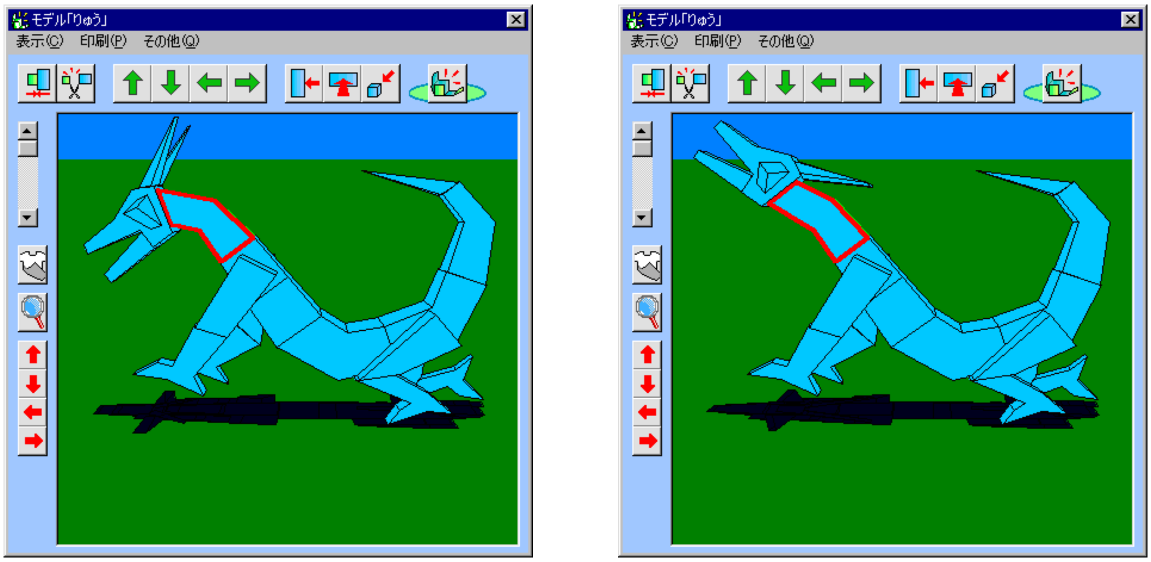


(a) Before Transfer (b) After Transfer

Figure 9: Drag of polyhedron

3.2. Modification of Design by Utilizing Subordinate Relation

Polyhedrons that are connected are subordinate to the polyhedron that was connected (called parent polyhedron in the present article). By deforming the parent polyhedron, all subsidiary polyhedrons are influenced. Design can also be modified with ease if taking subordinate relation of polyhedrons into consideration in designing a paper craft. An example is shown in Fig. 10. Design of the model can largely be modified as shown here.

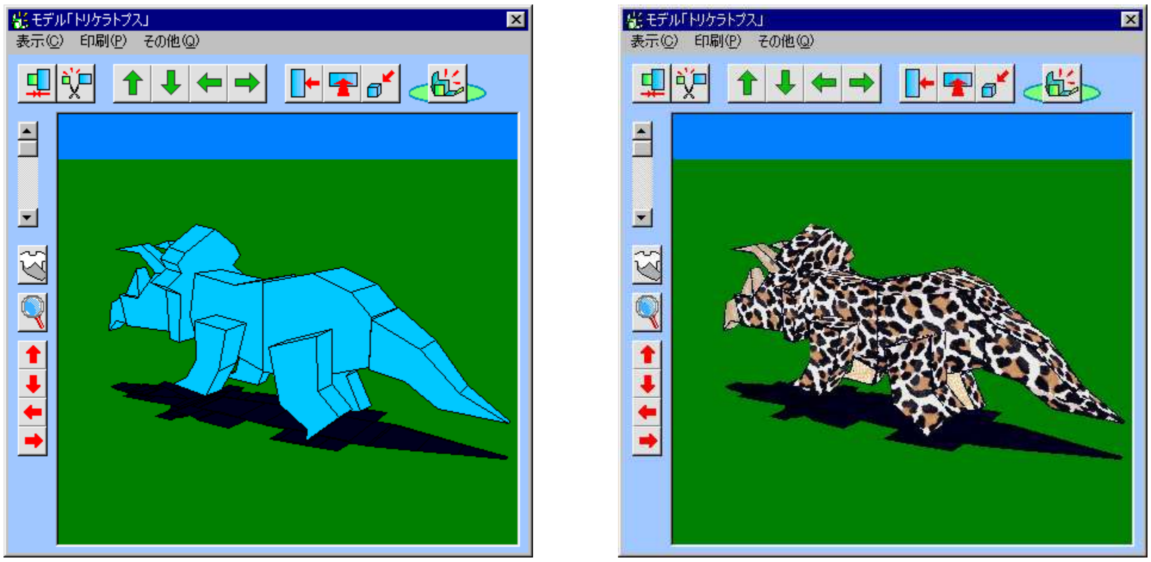


(a) Wrong at Neck (b) Right at Neck

Figure 10: Change of design utilizing subordinate relation

3.3. Pasting of Texture

Color and texture can be attached to fabricated models as shown in Fig. 11. Such colors and textures are pasted on the polyhedrons for each face as the unit. With this function, even a paper craft with simple structure can be finished to an article that gives realistic feeling.



(a) Monotone (b) Colored

Figure 11: Pasting of texture

3.4. Output Procedure of Paper Craft

On developed plans of the paper craft, "guidance" for connection is automatically calculated and attached to its interior as shown in Fig. 12. This clarifies sites of connection on mutual polyhedrons, and indicates that assembly is simply conducted by connecting faces with the same number written as guidance. Further, it has also described the shape of partner's face to be connected. These have been so devised so that users can immediately understand the connecting sites when assembling the model. An example of it is shown in Fig. 13.

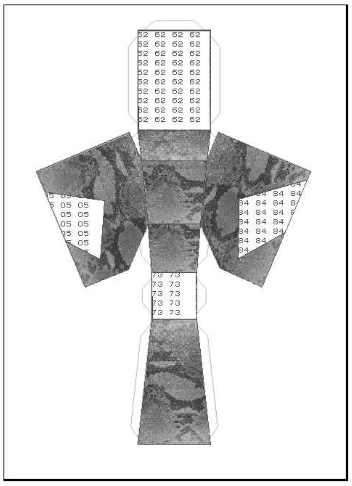


Figure 12: Guidance

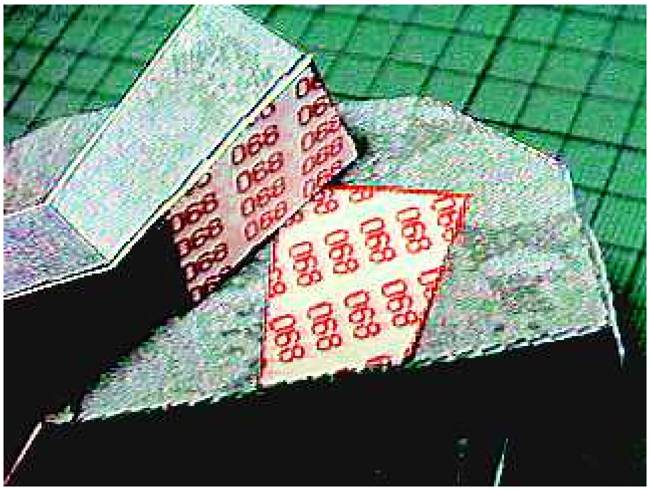
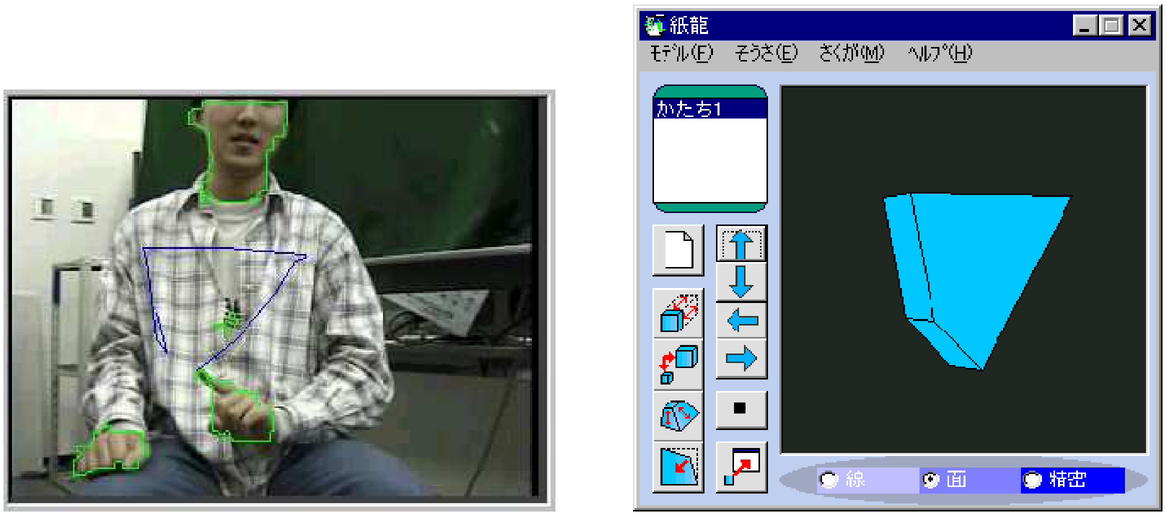


Figure 13: Display of connection site

4. Untouched input system

This software is also available in correspondence to the untouched input system on which the authors are studying [6, 7]. This made it possible to conduct a series of operation like design of paper craft using neither mouse nor keyboard. More of above-mentioned operations are those performed by gesture of the user. It also corresponds to direct gesture of the user. In forming polyhedron, in addition, the figure can be set with a fingertip as shown in Fig. 14.



(a) Designing Shapes in The Space (b) Generated Model with Fingertip

Figure 14: Shape designation of polyhedron with fingertip

5. Discussion

Paper crafts with complex figures could be created in a short period of time by combining polyhedrons in succession. Shown in Fig. 15 are samples of paper crafts designed with this software [8]. As seen from this figure, a polyhedron becomes a component of paper craft. This is a very important fact in assembly of paper craft. First, progressive state of assembly is very easy for users to know because assembly work can be successively completed by every polyhedron. Furthermore, individual polyhedrons are comparatively simple in the figure and such works as deforming or twisting are not needed. Because one can re specify or define a part as a unit even if assembly is failed, users can enjoy paper craft without fear of failure. Mutual connection of polyhedrons became very easy to understand, in addition, by delineating guidance that shows connecting sites of polyhedrons on the developed plan. As the practical result, even the user's first experienced assembly of paper craft could be safely complete with a sense of manipulating a puzzle. We have heard some comments about our software from many of our users such as easy handling and freely designing systems. Fig. 16 shows a scene of assembling by students. Newly designed models [9] are widely prevailing now in our country. From facts described above, this procedure is effective as a method that improves the assembling efficiency of the paper craft. Also, by designing figures of the paper craft using software, the paper craft that had so far been used mostly a passive experience it is now possible to experience the active pleasure of creating designs. It is believed that the practical use of personal computer could make the paper craft more familiar. In near future, we intend to develop cubic and corn bodies as often requested by the users of this software.

Figure 15: Examples

Figure 16: Assembling

6. Close

It has been proposed recently that education of promotion of sensibility and creativity is a desired goal. In comparison with prior educational practices,the time allowed for learning through requirements. In this circumstance, the paper craft assembly requires the student to imagine the completed state of the design and is most suitable as material for learning while experiencing structure of diagram or solid body. By learning joy in the process of creating a design it is expected that the process will deepen the comprehension of drawing and will be useful in the cultivation of artistic sentiments. It can provide a good opportunity to give familiarity with digital equipments through manipulation of software. The paper craft has developed from the paper culture of old Japan, and it is hoped that people, regardless of age or sex, will continue to become acquainted with. It is our pleasure that this procedure and software can help with this goal.

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