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(Citation)

Memoirs of the Graduate Schools of Engineering and System Informatics Kobe University, 7:14-16

(Issue Date)

2015

(Resource Type)

departmental bulletin paper

(Version)

Version of Record

(URL)

<https://hdl.handle.net/20.500.14094/81009185>



A Lampshade Design Method by Paper Folding and Luminance Distribution on the Lampshade Designed by the Method. -Skew Quadrilateral Membrane Folding Method-

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(Received December 26, 2015; Accepted January 7, 2016; Online published January 18, 2016)

Keywords: Paper folding, Skew quadrilateral, Lampshade, Luminance distribution, Illuminance

1. Introduction

Historically, Japanese traditional lampstand 'Andon', was manufactured from paper. And paper folding method was adopted into some Andon and western lampshade¹⁾. If we put non-flat texture on the surface of such lampshade with paper folding method, nonuniform luminance distribution appears on the surface according to basic laws of illuminance. Such nonuniform luminance on the surface of lampshade contributes to easier recognition of its shape and more attractive appearance.

Yoshimura/Diamond pattern²⁾ is one of the most typical paper folding methods in the field of lampshade design. This pattern is known as a structure of crashed cylinder and structure of building roof, and has been made good use in commercial lampshade products¹⁾. Yoshimura pattern structure includes a set of skew quadrilaterals which is not on a plane surface and each quadrilateral is constructed by two planar triangles. Consequently, lampshades manufactured with Yoshimura pattern have nonuniform luminance distribution overall, however, luminance distribution within a skew quadrilateral unit is discontinuous at boundary of two planar triangles which compose a skew quadrilateral unit.

Author found that similar shape can be constructed by modified Yoshimura pattern and develop the method to 'Skew Quadrilateral Membrane Folding' method. In this paper, author indicated principle of the proposed paper folding method at first. In the second, features of the shape made by proposed method and the luminance distribution on the shape are explained. Next, examples of applications of proposed method are indicated. Finally, an example of application of the shape made by proposed method in the field of education is explained.

2. Skew Quadrilateral Membrane Folding Method

The proposed paper folding method is based on Yoshimura pattern²⁾. Yoshimura pattern is one of the famous paper folding methods. The Yoshimura pattern has been applied to structure of building roof³⁾ and cylindrical Yoshimura pattern was considered as approximation of buckling of a circular cylindrical shell²⁾. Besides cylindrical Yoshimura pattern, dome Yoshimura pattern⁴⁾ had been proposed as well. As shown in Fig.1, development of cylindrical Yoshimura pattern has two sets of oblique parallel lines at even intervals for mountain fold and one set of horizontal parallel lines at even intervals for valley fold.

Cylindrical shape shown in Fig.1 appears after folding the development along with the lines drawn in the development and bending the development to attach bilateral sides without gap and overlap. In case of the shape made from

cylindrical Yoshimura pattern, each diamond on the development change its shape to skew quadrilateral unit and the unit is constructed by two planar triangles. Consequently, luminance distribution in the area of the unit is discontinuous at boundary of the two triangles.

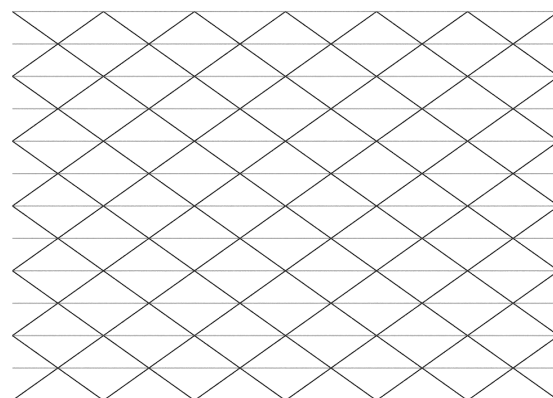


Fig. 1 A development of cylindrical Yoshimura pattern (upper, black lines for mountain fold and grey lines for valley fold) and cylindrical shape made from the development (lower)

As shown in Fig.2, similar shape appears after folding the development shown in Fig.1 along with only lines for mountain fold and bending it. Author named the shape constructed by skew quadrilaterals with mountain folds as 'Skew Quadrilateral Membrane Folding' (hereafter, SQMF). The shape shown in Fig. 2 is constructed by cylindrical SQMF method.



Fig. 2 A shape made by cylindrical SQMF method with point light source

In case of the shape made from cylindrical SQMF, each skew quadrilateral is constructed by continuous curved surface and illuminance distribution is continuous within area of a unit quadrilateral as shown in Fig. 2. From the viewpoint of shape, difference between two shapes is trivial, however, from the viewpoint of illuminance distribution, difference between two shapes is significant.

Though luminance on diffuse transmitting surface measured from outside is decided by direct illuminance and indirect illuminance of corresponding inner point, contribution of direct illuminance is higher considering relative variation of luminance distribution. Direct illuminance given by point light source can be calculated by basic illuminance laws, 'Inverse square law of illuminance' and 'Cosine law of illuminance'.

3. Luminance Distribution on the Shape Made by SQMF Method

Fig. 3 shows measured luminance distribution on the surface of the shape made by Yoshimura pattern and SQMF method. The luminance distribution is already explained in chapter 2 and continuous distribution is intuitively recognized with the figure. However, more precise recognition is possible with Fig. 3. In case of luminance distribution on the surface made by SQMF method, luminance values of upper side and that of lower side are quite different and buffer zone exists between upper side and lower side to connect values of upper side and that of lower side continuously at almost all quadrilateral units.

In this experiment, LED lamp which can be considered as point light source was used as light source of the shape. If bigger light source is used, change of luminance distribution becomes unclear because inner illuminance distribution of the shape does not follow basic illuminance laws for point light source.

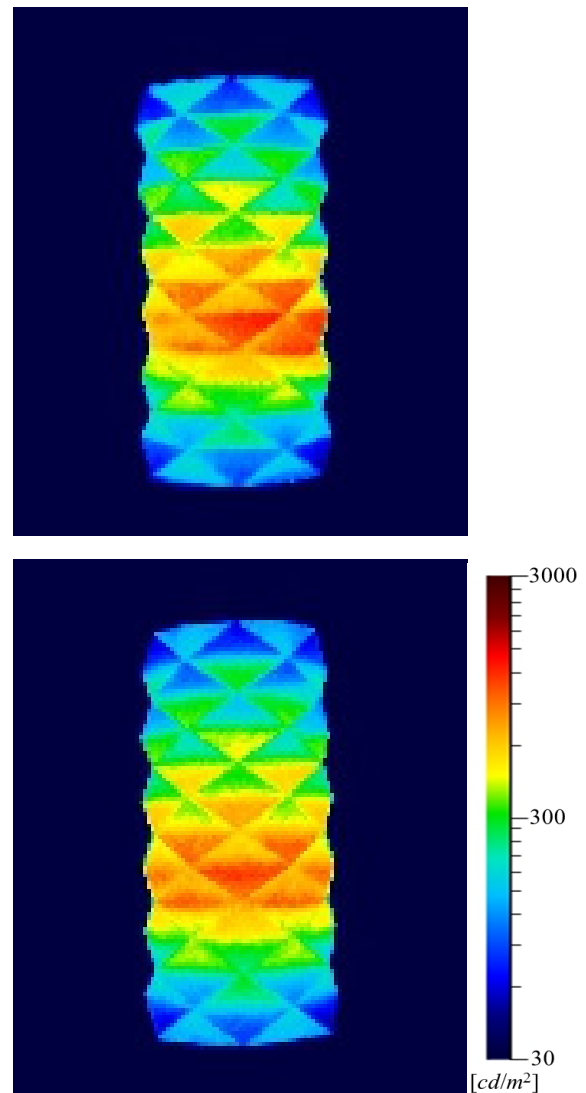


Fig. 3 Measured luminance distribution on the surface of the shape made by original Yoshimura pattern (upper) and SQMF method (lower).

4. Variations of SQMF Method

As explained in chapter 2, if unit diamonds with valley fold line are located radially, dome shape can be obtained. Dome type Yoshimura pattern is a variation of cylindrical Yoshimura pattern. As same as dome type Yoshimura pattern, dome shape can be obtained by dome type SQMF method. And if unit diamonds are located to make bigger triangle, conical SQMF will appear. Each quadrilateral unit is covered by a curved surface as well in both cases. Fig. 4 shows examples of dome type SQMF and Fig.5 shows that of conical SQMF.

5. An Example of Application of the Shape Made by SQMF in the Field of Education

As the manufacturing process of the shape made by SQMF method is simple enough, SQMF has large potential in the field of education. On 12th December 2014, the special lecture for high school students was held at department of engineering, Kobe university. 13 high school students were joined the lecture. In the lecture, basis of differential geometry

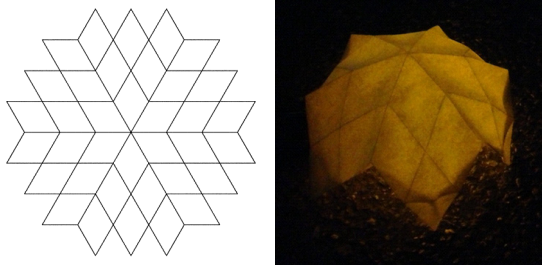


Fig. 4 An example of dome type SQMF

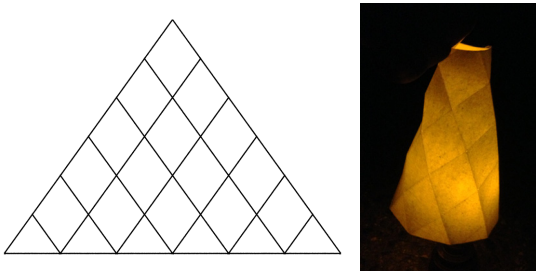


Fig. 5 An example of conical SQMF

was explained at first. Then the students were requested to manufacture lampshades made by cylindrical SQMF by themselves. Finally, basic laws for illuminance were explained and the students put their own lampshades around candle fire to make sure the laws.

As manufacturing process of the lampshades is extremely simple, all participating students could easily construct the lampshades within 75 minutes including the time for lecture. Fig. 6 shows an example of the lampshades manufactured by the participating student.



Fig. 6 An example of lampshade with candle light manufactured by the high school student who participating special lecture in Kobe university

6. Conclusion

In this paper, author indicated principle of the proposed paper folding method at first. In the second, features of the shape made by proposed method and the luminance distribution on the shape are explained. Next, examples of applications of proposed method are indicated. Finally, an example of application of the shape made by SQMF in the field of

education is explained.

It seems that there are many possibilities about application of SQMF method. Left-right asymmetry SQMF method can be combined with non-parallel SQMF method. Outlines forms for cylindrical SQMF are not limited to simple cylinder. Edge of the shape made from SQMF method can be connected with the combined developable shapes which are proposed by Suzuki⁵⁾. Author would like to continue the research about SQMF method to develop further application of the method.

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Note

This paper was presented at the 8th Lighting Conference of China, Japan and Korea (Aug. 2015, Kyoto Japan) and was awarded 'One of the best papers' award.