J Wood Sci (2015) 61:19–27
DOI 10.1007/s10086-014-1439-6

ORIGINAL ARTICLE

Evaluation of visual impact of multiple image characteristics observed in edge-grain patterns

Masashi Nakamura · Saki Nakagawa · Takato Nakano

Received: 26 June 2014 / Accepted: 9 October 2014 / Published online: 21 October 2014

Abstract Twenty distinct computer-generated softwood-like monochrome edge-grain patterns were printed on matte paper. Four image characteristics including mean growth ring width, growth ring width fluctuation, growth ring contrast, and shading contrast were embedded in the patterns. These image characteristics were expressed numerically by line profile and multiresolution contrast analyses. Five visual impressions, varied, agreeable, vague, showy, and natural, of these patterns on 30 subjects were evaluated by ranking. To determine the importance of each image characteristics on the impressions, a multiple regression analysis was conducted by attributing a criterion variable to an impression and predictor variables to all four image characteristics. This analysis revealed the impacts of the four image characteristics on each impression quantitatively. The results suggested that shading contrast was one of the useful indicators to evaluate surface harmony or homogeneity related to varied impression. Although growth ring width fluctuation had been considered as an important visual feature of wood, its influence on the impressions was extremely small compared with the other three characteristics.

Keywords Edge-grain pattern · Sensory evaluation · Image characteristics · Visual impression · Multiple regression analysis

M. Nakamura (✉) · S. Nakagawa · T. Nakano
Graduate School of Agriculture, Kyoto University, Kitashirakawa Oiwake-cho, Sakyo-Ku, Kyoto 606-8502, Japan
e-mail: nakamasa@kais.kyoto-u.ac.jp

Introduction

Various visual characteristics of wood, which are broadly classified into warm colors, varied grain patterns, and mellow gloss, contribute to the unique appearance of wood that may psychologically benefit humans [1, 2]. To determine the nature of these desirable effects, relationships between wood surface properties and visual impressions evoked in human observers by these surfaces have been examined. Broman [3–5] and Nyrud et al. [6, 7] assessed the surface properties using subjective evaluations by human graders, acquired human observers to evaluate the visual impression, and investigated the relationships among the data using various multivariate analyses. Nakamura et al. [8–10] objectively extracted some pictorial features of lumber surfaces by image analysis and reported the relationships between image characteristics and visual impressions. Recently, Akiyama et al. [11] defined impression parameters based on a two-dimensional Fourier power spectrum of the wood grain pattern and tried to predict the appropriate parameters for a given impression.

Although these studies used real wood specimens or real wood images as the visual stimuli to approach the issue, Okajima et al. [12–14] or Nakamura et al. [15] adopted wood grain patterns generated by computer graphics techniques, i.e., CG grains. An experimental benefit of CG grains compared with real wood resides in the ability to methodically prepare purpose-built visual stimuli without being affected by the inherent variety of wood. In other words, it would enable to evaluate the effect of a special visual characteristics of wood in more pure form. Okajima et al. [12] focused on the geometric parameters of the edge-grain patterns. They generated various stripes as line drawings and assessed the effect of changing stripe intervals on visual impressions in view of characteristics of

Fourier power spectra of the patterns. They reported that stripes in fluctuated interval according to 1/*f* fluctuation gave more "Natural" impression than the equal interval or Japanese traditional stripes, and "Natural" stripes were also "Agreeable" ones. Okajima et al. [13, 14] also drew various edge-grain and flat-grain patterns mathematically to examine the visual impressions of these patterns, and pointed out that "Wood-looking" was a key to other positive impressions such as "Natural" and "Agreeable". While Okajima's patterns consisted of the geometric line drawings, Nakamura et al. [15] used gray scale CG grains involving various light and shade. They reported that lightness variations at low spatial frequency, such as shading, intensely affected "Natural" impression. Furthermore, Nakamura et al. [16] prepared edge-grain pictures whose lightness contrasts were modified mathematically by image processing and demonstrated that lightness changes in edge-grain patterns impacted visual impressions such as "Varied" and "Elegant".

Most studies using CG grain methodology have separately focused on the geometric parameters and the gray-level parameters of wood. Therefore, interactions and balances between both parameters on visual impressions remain unknown.

Here, monochrome edge-grain patterns were mathematically drawn by a pattern generator. These patterns embedded four image characteristics including mean growth ring width, growth ring width fluctuation, growth ring contrast, and shading contrast. The first two characteristics were the geometric parameters reported by Okajima et al. [12], and the others were the gray-level parameters suggested by Nakamura et al. [15, 16]. This study aims to demonstrate the psychophysical effects of these image characteristics associated to two categories of the geometric and gray-level parameters on visual impressions received by human observers. To extract universal relationships between the visual impressions and the image characteristics, the weight of each image characteristics on a given impression was evaluated by multiple regression analysis.

Materials and methods

Specimens

Twenty softwood-like edge-grain patterns (Fig. 1) were produced using an "in house" pattern generator program. To limit input parameters within the four image characteristics and simplify the issue, two restrictions were applied, i.e., all edge-grain patterns should be represented by parallel straight lines without vertical fluctuations and printed in monochrome to eliminate chromatic information. Accordingly, the pattern generator mainly calculated the growth ring widths and lightness changes of the edge-grain patterns and created a line profile representing increases and decreases in lightness perpendicular to the grain. From input parameters related to the mean width and fluctuation ratio of the growth rings, the generator defined each growth ring width and incorporated fluctuations into these widths using uniform random numbers. The generator also simulated the lightness changes by two approaches (Fig. 2). Profiles for the earlywood to latewood lightness transition in each growth ring mimicked logarithmic curves with similar heights, while smooth lightness undulation (i.e., shading) was expressed through multisinusoidal curves. Finally, the generator simply stretched the one-dimensional line profile data on a two-dimensional image from top to bottom. Therefore, all grains in the image corresponded to parallel straight lines from top to bottom. Image sizes were 4600 and 6500 pixels in horizontal and vertical directions, respectively. The number of growth rings in each edge-grain pattern ranged from 43 to 235.

Printed specimens were prepared from these generated images as visual stimuli to be presented in sensory evaluation. All specimen resolutions and sizes were adjusted to 600 dpi and 195 × 275 mm through a photo-retouching software (Photoshop CS1, Adobe Systems Inc., Tokyo, Japan) before printing on A4 size matte paper (SG-101, Canon Inc., Tokyo, Japan) using an ink-jet printer (PIXUS 860, Canon Inc., Tokyo, Japan). These monochrome patterns exhibited similar dimensions to a real edge-grain pattern. Because each pixel displayed a unique gray level (8 bit integer, 0–255), it was converted to the metric lightness L^* in the $L^*a^*b^*$ color system using the quintic regression equation formulated previously [16].

$$L^* = -466.5g^5 + 1381g^4 - 1545g^3 + 755.5g^2 - 40.44g + 7.804, \quad (1)$$

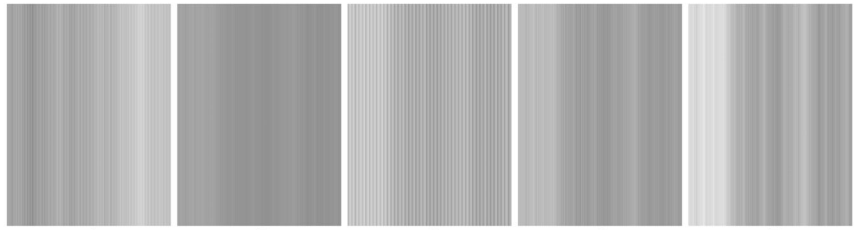
where g is the standardized gray level ranging from 0 to 1. The mean lightness of each pattern spanned from 60.37 to 71.65 and the darkest pattern was P, while the brightest was Q. These differences in the mean lightness depended on the degree of shading.

Image characteristics

The computer-generated edge-grain patterns described above differed from each other according to mean growth ring width, growth ring width fluctuation, growth ring contrast, and shading contrast. The mean growth ring width and its fluctuation, represented in mm, were calculated from the scanned line profile of each pattern (Fig. 2). Here,

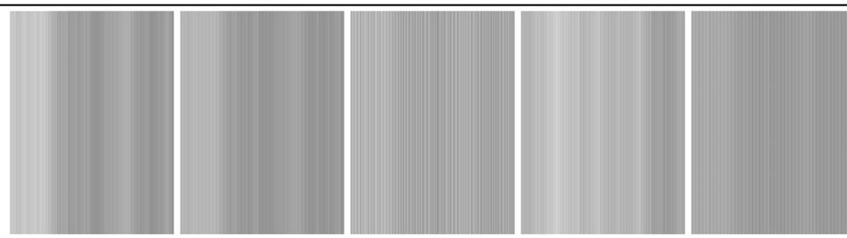
Fig. 1 Specimen images of edge-grain patterns. Specimen sizes are 195 × 275 mm. *M* mean growth ring width, *F* growth ring width fluctuation, C_G growth ring contrast, C_S shading contrast

Image



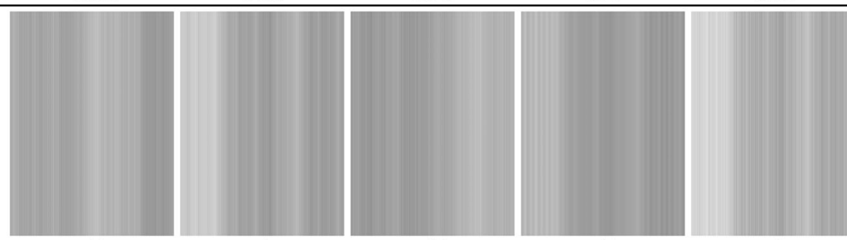
Name	A	B	C	D	E
M [mm]	3.34	2.13	4.23	2.11	2.13
F [mm]	1.65	1.02	0.00	1.61	1.02
C_G	4.61	2.89	9.52	5.47	5.17
C_S	7.25	4.01	7.12	7.55	14.09

Image



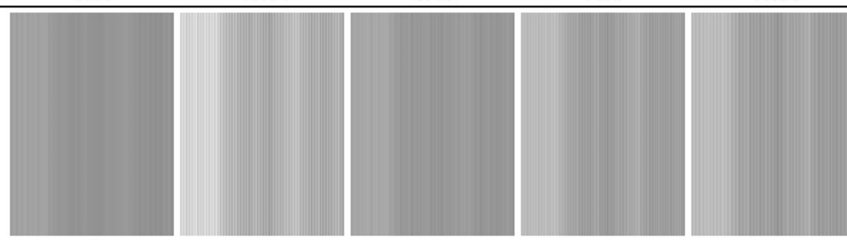
Name	F	G	H	I	J
M [mm]	3.40	4.23	3.40	3.34	4.23
F [mm]	2.50	0.00	2.50	1.65	0.00
C_G	2.75	2.75	2.75	2.75	2.75
C_S	10.93	7.63	3.75	6.21	3.82

Image



Name	K	L	M	N	O
M [mm]	2.13	2.12	2.08	0.85	2.13
F [mm]	1.02	0.00	1.02	0.00	1.06
C_G	5.39	5.39	5.45	6.56	10.59
C_S	6.05	10.94	6.18	7.61	10.60

Image



Name	P	Q	R	S	T
M [mm]	0.85	3.39	0.82	3.39	4.33
F [mm]	0.00	0.00	0.38	1.57	1.74
C_G	3.43	9.71	7.53	5.08	4.83
C_S	4.02	10.32	4.01	7.56	7.54

the fluctuation was defined as the difference between the maximum and minimum growth ring widths.

The lightness change in growth rings and shading were evaluated by multiresolution contrast analysis (MRCA), a new image analysis method proposed by Nakamura et al. [16–18]. In this method, lightness differences between contiguous local areas with a given size were calculated in various places within an image by changing the size of the areas being measured. Here, one-dimensional MRCA was applied to the edge-grain patterns, as reported previously [16]. MRCA provides a characteristic curve, or a contrast spectrum, which shows contrast values as a function of the

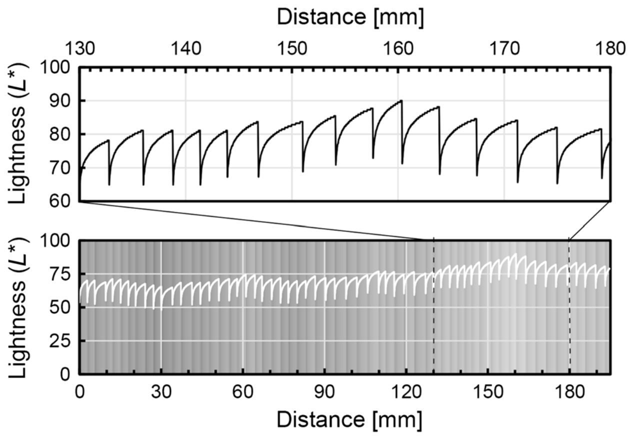


Fig. 2 Typical line profile of softwood-like edge-grain patterns. The lightness transition from earlywood to latewood in each growth ring is expressed using logarithmic curves with similar heights (*upper*). Relatively smooth overlapping lightness changes (i.e., shading) are expressed using multisinusoidal curves (*lower*)

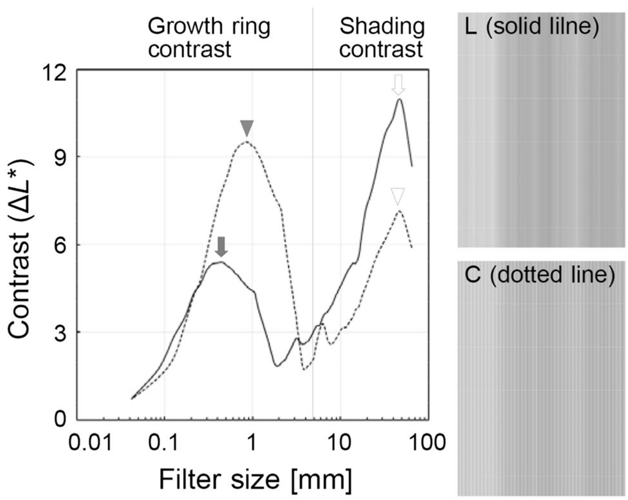


Fig. 3 Typical contrast spectra of edge-grain pattern C (*dotted*) and L (*solid*) obtained by multiresolution contrast analysis. To define growth ring contrast and shading contrast, the threshold was set at a filter size of 5 mm. Details are provided in the text

smooth filter size. Figure 3 shows two photographs of specimens C and L. At first glance, specimen C visibly shows wider and clearer edge-grain patterns than specimen L. However, the shadings of specimen L are deeper than specimen C. These differences in appearance are reflected in their contrast spectra.

In Fig. 3, closed symbols over the curves represent contrast peaks in a relatively small filter size region. Peak positions approximately correspond to dark latewood widths. Consequently, peak heights reflect lightness differences between latewood and earlywood, i.e., growth ring contrast. Specimen C displays a higher peak position than specimen L because it comprises wider latewood than specimen L. The difference in peak heights between specimen C and L denotes a disparity in grain clarity between patterns. Conversely, open symbols in the relatively large filter size region highlight contrast peaks connected to shading, because shading is smooth lightness undulation perpendicular to the grain with relatively long wave length (low spatial frequency). Peak heights correspond to mean undulation of lightness (i.e., shading contrast). The difference in peak heights between specimen C and L corresponds to the visible difference in shading depth between the patterns. In particular, specimen L exhibits more noticeable changes in shading than specimen C. Considering these properties, a threshold was set at a filter size of 5 mm to divide the spectrum into growth ring and shading contrast regions, enabling the detection of one peak in each region.

Mean growth ring width (M), growth ring width fluctuation (F), growth ring contrast (C_G), and shading contrast (C_S) were extracted from each edge-grain pattern using the techniques described above. These data are shown in Fig. 1, and the relationships between the mean growth ring width and its fluctuation and between growth ring contrast and shading contrast are shown in Fig. 4. Figure 4 shows that the four image characteristics associated with the geometric and gray-level parameters were satisfactorily embedded in each edge-grain pattern by the pattern generator developed in the present study. For example, specimens B, E, and O display almost the same mean growth ring width and fluctuation but different contrast values. Moreover, specimens K and M showed nearly identical image characteristics (Fig. 4) despite their fairly different appearances (Fig. 1). This is because their shadings were expressed by different sinusoidal parameters.

Sensory evaluation

Sensory evaluations were conducted to investigate the visual impressions of the edge-grain patterns. A questionnaire asked the subjects to rank their impressions using five adjectives, i.e., varied, agreeable, vague, showy, and natural. These impression words were translated into Japanese on the questionnaire form, i.e., Henkani-tonda, Kanjino-yoi, Boyatto-shita, Hade-na, and Shizen-na. On the selection of the adjectives, candidate words were gathered up by succeeding to some adjectives used in our former reports [15, 16] or referring to relevant studies, especially Yasuda et al. [19]. As Yasuda collected and sorted many adjectives related to visual characteristics of wood-based materials, their article was a kind of database for our study. Through pretests to check the ease of reply by the subjects, the candidate words were narrowed down to the five.

Here, each subject was requested to examine a set of specimens, which were randomly arranged on a black table top, and to sort them in order of the degree of each impression listed on the questionnaire form. A series of tasks including breaks took approximately 50 min to

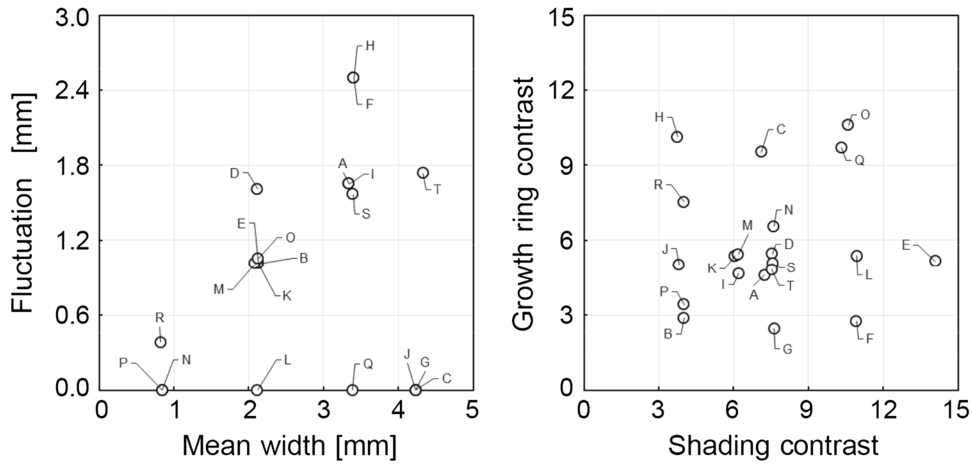


Fig. 4 Relationships between mean growth ring width and fluctuation (*left*), and growth ring contrast and shading contrast (*right*). *Capital letters* correspond to specimen names (Fig. 1)

Table 1 Correlation matrix of image characteristics and impressions

Image characteristics	Mean width	Fluctuation	Growth ring contrast	
Fluctuation	0.231			
Growth ring contrast	−0.013	−0.081		
Shading contrast	0.060	0.039	0.074	
Impressions	**Varied**	**Agreeable**	**Vague**	**Showy**
Agreeable	0.047			
Vague	−0.397	0.757***		
Showy	0.742***	−0.543*	−0.890***	
Natural	0.248	0.878***	0.578***	−0.355

Japanese translations of adjectives are as follows: varied (*Henkani-tonda*), agreeable (*Kanjino-yoi*), vague (*Boyatto-shita*), showy (*Hade-na*), natural (*Shizen-na*)

* $p < 0.05$, *** $p < 0.001$

complete. The table was illuminated by neutral white fluorescent ceiling lamps at a surface illuminance of approximately 1100 lx. Thirty students (18 male and 12 female, mean age 23.0 ± 1.6, mean visual acuity 1.0 ± 0.2, and including eyeglass or contact lens users) answered the questionnaire. They observed the specimens from a distance of approximately 800 mm. Sensory data obtained by the ranking method were statistically scaled based on the mean standard deviation [20].

Results and discussion

Correlation analysis

Simple correlation coefficients between the four image characteristics are listed in the upper part of Table 1. All coefficient values were small, suggesting that these image characteristics were independent from each other and were consequently suitable predictor variables for the impressions. Correlation coefficients between the five impressions are also shown in the lower part of Table 1. The showy impression showed highly positive correlation with the varied impression but a highly negative correlation with the vague impression. Agreeable and natural impressions presented a highly positive correlation, implying that the visual naturalness of the patterns easily induced an agreeable impression.

Twenty scatter diagrams expressing the relationships between the four image characteristics and the five impressions are shown in Fig. 5. Although about half of these diagrams showed statistically significant linear correlations, their linearities were not sufficient and data points were vertically scattered. For example, the mean width and the showy impression display a linear relationship ($r = 0.624$), in which an increase in mean growth ring width results in a showier impression. However, the showy impressions of patterns presenting the same mean growth ring width were fairly different from each other (vertical scattering). Similar tendencies were observed for the other impressions. In addition, some impressions exhibited multiple significant correlations with the image characteristics. For instance, the showy impression was related with the mean growth ring width, the growth ring contrast, and the shading contrast. This implies that visual impressions are difficult to explain using a single parameter such as the mean growth ring width.

In Fig. 5, the fluctuation of growth ring width did not correlate significantly with any impression although it has often been advertised as the dominant factor for the appearance of grain patterns. This suggests that the influence of the fluctuations on the impressions is relatively low compared with the other three image characteristics although the growth ring width fluctuation is one of the unique visual characteristics of wood.

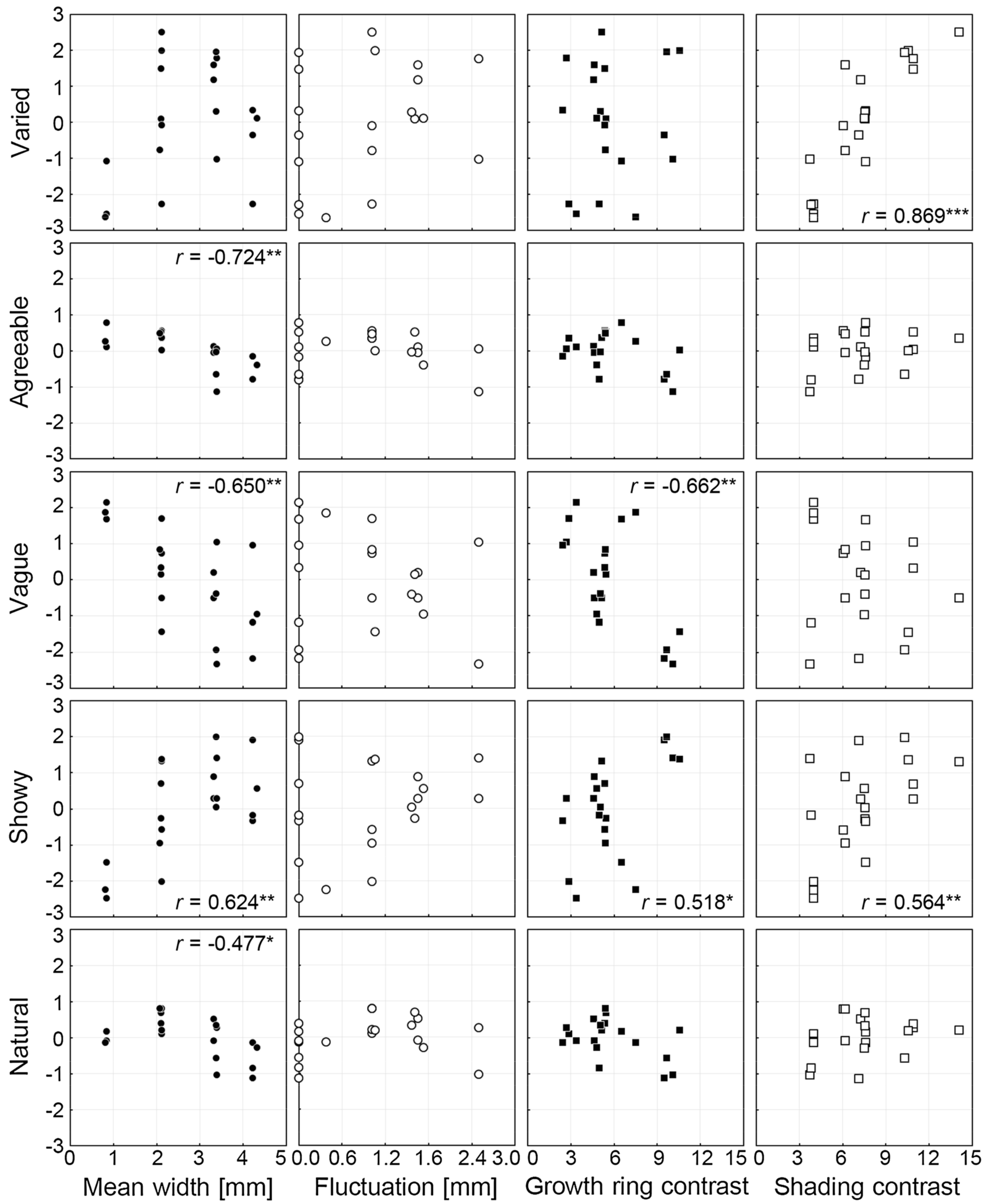


Fig. 5 Relationships between four image characteristics and five impressions (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$). Japanese translations of English adjectives are as follows: varied (*Henkani-tonda*), agreeable (*Kanjino-yoi*), vague (*Boyatto-shita*), showy (*Hade-na*), natural (*Shizen-na*)

Multiple regression analysis

Next, a multiple regression analysis was applied to the five sensory data and four image characteristics to objectively determine the effect of each image characteristic on the impressions. In this analysis, an individual impression and the four image characteristics were set as criterion variable (dependent variable) and predictor variables (independent variables), respectively. Typically, a multiple regression model that involves fewer predictor variables is considered better. Therefore, a statistically insignificant predictor variable tends to be removed from the proposed model, and a new model using fewer predictor variables is tested. Here, however, all four predictor variables were

Table 2 Multiple regression analysis results

Criterion variable	Predictor variable				Intercept	R^2
	M	F	C_G	C_S		
S_{Varied}						
Partial regression coefficient	0.276	0.401	0.045	0.481**	−4.936**	0.859
Standardized partial regression coefficient	0.196	0.211	0.068	0.844		
$S_{Agreeable}$						
Partial regression coefficient	−0.343**	0.028	−0.095**	0.054*	1.067**	0.798
Standardized partial regression coefficient	−0.758	0.045	−0.448	0.295		
S_{Vague}						
Partial regression coefficient	−0.757**	−0.129	−0.375**	−0.059	4.805**	0.892
Standardized partial regression coefficient	−0.632	−0.080	−0.667	−0.121		
S_{Showy}						
Partial regression coefficient	0.666**	0.179	0.271**	0.229**	−5.249**	0.918
Standardized partial regression coefficient	0.575	0.115	0.498	0.488		
$S_{Natural}$						
Partial regression coefficient	−0.277**	0.191	−0.102*	0.065	0.695	0.619
Standardized partial regression coefficient	−0.569	0.291	−0.447	0.330		

S_{Varied}, $S_{Agreeable}$, S_{Vague}, S_{Showy}, and $S_{Natural}$ correspond to sensory values for varied (*Henkani-tonda*), agreeable (*Kanjino-yoi*), vague (*Boyatto-shita*), showy (*Hade-na*), and natural (*Shizen-na*) impressions, respectively (Italics in parentheses is corresponding Japanese.)

M mean growth ring width, F growth ring width fluctuation, C_G growth ring contrast, C_S shading contrast

* $p < 0.05$, ** $p < 0.01$

incorporated into every regression model. An intercomparison of the standardized partial regression coefficients facilitates this evaluation. All calculations were performed using a statistical analysis software (JMP 9, SAS Institute Japan, Tokyo, Japan).

The results are summarized in Table 2. In the absence of multicollinearity among the predictor variables, the following five regression equations were obtained.

$$S_{Varied} = 0.276M + 0.401F + 0.045C_G + 0.481^{**}C_S - 4.936, \quad (2)$$

$$S_{Agreeable} = -0.343^{**}M + 0.028F - 0.095^{**}C_G + 0.054^{*}C_S + 1.067, \quad (3)$$

$$S_{Vague} = -0.757^{**}M - 0.129F - 0.375^{**}C_G - 0.059C_S + 4.805, \quad (4)$$

$$S_{Showy} = 0.666^{**}M + 0.179F + 0.271^{**}C_G + 0.229^{**}C_S - 5.249, \quad (5)$$

$$S_{Natural} = -0.277^{**}M + 0.191F - 0.102^{*}C_G + 0.065C_S + 0.695, \quad (6)$$

where S is the predicted value of the impression and the subscript indicates the corresponding impression, and asterisks denote the significant level of each coefficient ($^*p < 0.05$, $^{**}p < 0.01$). As indicated by the large contribution coefficients (R^2 values), all regression equations fitted quite well except for the natural impression (Eq. 6). The relationships between observed and predicted impressions shown in Fig. 6 also provide information on the congruity of the models.

The shading contrast showed a dominant influence on the varied impression. This result agrees with a previous report [16] suggesting that contrast values calculated by MRCA at relatively large filter sizes strongly correlated with the varied impressions of real edge-grain patterns.

The impact of shading on the remaining four impressions was lower than on the varied impression. Conversely, the influence of the mean growth ring width and the growth ring contrast on these impressions rose relatively. Although this impact differed for every impression, the mean growth ring width was the dominant variable for agreeable, vague, showy, and natural impressions. For example, edge-grain patterns with narrower growth rings and lower growth ring contrast is expected to easily induce more vague impression. Alternatively, the patterns displaying wider growth rings and higher contrasts may provide the observers a higher impression of showiness.

Though the multiple regression model was applied to explain the visual impression by the four characteristics in the present study, similar approach had already been examined by Høibø and Nyrud [7]. They used knotty deck materials, not the edge-grain patterns, as the visual stimuli and found out surface homogeneity was a very important factor for consumers' preference to wood products. They

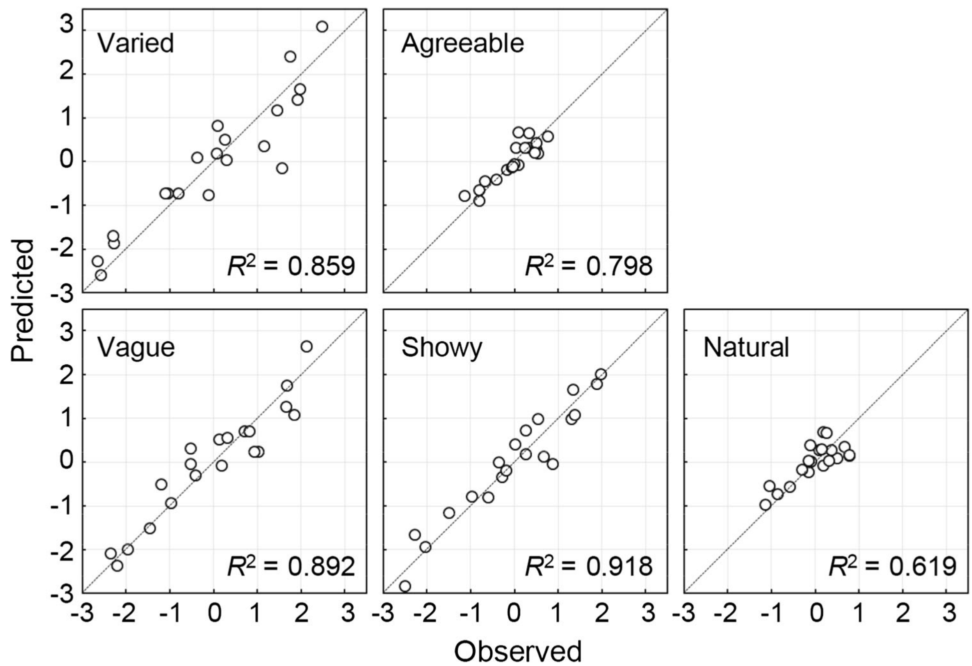


Fig. 6 Relationships between observed and predicted impressions. Japanese translations of English adjectives are as follows: varied (*Henkani-tonda*), agreeable (*Kanjino-yoi*), vague (*Boyatto-shita*), showy (*Hade-na*), natural (*Shizen-na*)

exhibited that homogeneity was a function of visual characteristics of the surface. In their partial least squares regression model, six characteristics measured by the sensory panel including stains, surplus color, knot shape, dry knots, spike knots, and knot checks were employed as independent variables. Also in the present study, the surface homogeneity of the edge-grain patterns probably affected varied impression. Thus, the shading contrast will be one of the useful indicators to evaluate the surface homogeneity numerically, for varied impression was mainly influenced by the shading contrast as shown in Table 2.

Broman [5] also used knotty wood surfaces as the visual stimuli and concluded that the degree of harmony and activity was one of the important aesthetic properties for consumers' preference to wood products. Broman's activity was expressed by the linear combination of six pairs of sensory data: interesting/uninteresting, stimulating/boring, rich/empty, lively/rigid, contrasty/indifferent, and eventful/uneventful. At a glance these sensory words suggest the correlation with varied impression in the present study. Actually, Nyrud et al. [6, 7] pointed out that Broman's concept of harmony was related to their surface homogeneity, and they expected the harmony or homogeneity could be modeled using wood properties. An investigation of the relationships among varied impression, homogeneity or harmony, and the shading contrast would be a noteworthy and interesting study.

Finally, we mention about the visual effect of the growth ring width fluctuation. In Japan, the fluctuation of growth ring width has been considered as one of the important aesthetic properties of wood since Musha had demonstrated the existence of $1/f$ fluctuation in grain patterns in his book [21]. And the results of Okajima et al. [12] confirmed this concept. However, this fluctuation hardly contributed to the five impressions in the present study. The visual influence of the growth ring width fluctuation will be actually very small in comparison with the gray-level properties, i.e., the growth ring contrast and the shading contrast.

Conclusions

To demonstrate the psychophysical effects of edge-grain patterns on visual impressions in human observers, 20 edge-grain patterns were generated from computer graphics, and their visual impressions were assessed by sensory evaluation. Four image characteristics including the mean growth ring width, the growth ring width fluctuation, the growth ring contrast, and the shading contrast were embedded in these edge-grain patterns, facilitating an investigation of relationships between visual impressions and image characteristics by correlation analysis and multiple regression analysis. These analyses provided five equations and revealed the impact of all four image characteristics on each impression. Although the fluctuation of growth ring width has been considered to be one of the most influential visual characteristics of wood, its effect on the impressions was extremely small compared with the other three image characteristics. Whereas the shading contrast was not only closely related to varied impression, it is probably also one of the useful indicators to evaluate the surface harmony or homogeneity.

The connection between visual impression data and the balance of image characteristics of wood was considerably restrictive, but was achieved in the present study. Using similar methodology to analyze the relationships between various visual impressions and image characteristics of other surfaces (flat-grain, knotty surface, and so on) would be of interest for future studies.

Acknowledgments This study was partly supported by JSPS KAKENHI Grant Number 24380093.

References

1. Nakamura M (2012) Appearance of wood and wooden interior (in Japanese). Mokuzai Gakkaishi 58:1–10
2. Nyrud AQ, Bringslimark T (2010) Is interior wood use psychologically beneficial? A review of psychological responses toward wood. Wood Fiber Sci 42:202–218
3. Broman NO (1995) Attitudes toward Scots pine wood surfaces: a multivariate approach. Mokuzai Gakkaishi 41:994–1005
4. Broman NO (1996) Two methods for measuring people's preferences for Scots pine wood surfaces: a comparative multivariate analysis. Mokuzai Gakkaishi 42:130–139
5. Broman NO (2001) Aesthetic properties in knotty wood surfaces and their connection with people's preferences. J Wood Sci 47:192–198
6. Nyrud AQ, Roos A, Rødbotten M (2008) Product attributes affecting consumer preference for residential deck materials. Can J Forest Res 38:1385–1396
7. Høbiø O, Nyrud AQ (2010) Consumer perception of wood surfaces: the relationship between stated preferences and visual homogeneity. J Wood Sci 56:276–283
8. Nakamura M, Masuda M, Hiramatsu Y (1994) Visual factors influencing psychological images of woods and stones (in Japanese). Mokuzai Gakkaishi 40:364–371
9. Nakamura M, Masuda M, Imamichi K (1996) Description of visual characteristics of wood influencing some psychological images (in Japanese). Mokuzai Gakkaishi 42:1177–1187
10. Nakamura M, Sakai T, Masuda M (2002) Visual characteristics influencing visual hardness of wood (in Japanese). J Soc Mater Sci Jpn 51:398–403
11. Akiyama R, Aoyama H, Oya T (2014) Study on digital design method to generate wood grain pattern representing required impression (in Japanese). J Jpn Soc Precis Eng 80:484–490
12. Okajima T, Kubo T, Noda K, Fujibayashi K (1985) A spectral analysis of stripes and its application to visual effects of architectural stripe patterns (in Japanese). J Struct Constr Eng Trans Archit Inst Jpn 356:16–23
13. Okajima T, Wakabayashi S, Noda K, Konishi T (1986) A geometrical analysis of the grain of wood and generating its patterns (in Japanese). J Struct Constr Eng Trans Archit Inst Jpn 369:9–15
14. Okajima T, Wakayama S, Noda K, Konishi T (1987) Grain pattern and its psychological effect (in Japanese). J Struct Constr Eng Trans Archit Instit Jpn 377:1–7
15. Nakamura M, Masuda M (1995) Visual characteristics of shadings in edge-grain patterns (in Japanese). Mokuzai Gakkaishi 41:301–308
16. Nakamura M, Miyake Y, Nakano T (2012) Effect of image characteristics of edge-grain patterns on visual impressions. J Wood Sci 58:505–512
17. Nakamura M, Masuda M, Shinohara K (1998) Multiresolutional image analysis of wood and other materials. J Wood Sci 45:10–18
18. Nakamura M, Matsuo M, Nakano T (2010) Determination of the change in appearance of lumber surfaces illuminated from various directions. Holzforschung 64:251–257
19. Yasuda A, Masuda M, Maku T (1978) Studies on the visual characteristics of wood based materials—factor analysis on the visual image of the interior wall materials (in Japanese). Wood Res Rev 12:81–101
20. Nakamura M, Masuda M (1995) Simplified method for statistical rating of sensory data (in Japanese). Wood Ind 50:18–21
21. Musha T (1980) World of fluctuation—wonder of 1/*f* fluctuation in nature (in Japanese). Kodansha Blue Backs, Tokyo, pp 129–134