https://doi.org/10.2352/issn.2169-2629.2020.28.4

A study on attributes for 2.5D print quality assessment

Altynay Kadyrova, Vlado Kitanovski, Marius Pedersen;
Department of Computer Science, Norwegian University of Science and Technology, Gjøvik, Norway

Abstract

Quality assessment is performed through the use of variety of quality attributes. It is crucial to identify relevant attributes for quality assessment. We focus on 2.5D print quality assessment and its quality attributes. An experiment with observers showed the most frequently used attributes to judge quality of 2.5D prints with and without reference images. Colour, sharpness, elevation, lightness, and naturalness are the top five the most frequently used attributes for both with and without reference cases. We observed that content, previous experience and knowledge, and aesthetic appearance may impact quality judgement.

Introduction

Material appearance is important in different applications such as printing, computer graphics, and cultural heritage. The attributes that define material appearance and its Quality Assessment (QA) are important. They may vary from application to application. In this work, we focus on QA of 2.5D prints and we aim to investigate their quality attributes. With respect to commercial 2D printing (offset lithography or digital printing), ISO 12647-2 [1] and ISO/TS 15311-1/2 [2-3] by pointing to the ISO 18621 [4] family are established standards in the industry. However, for other applications, there is no consensus regarding which attributes are the most important ones for QA of 2D prints [5] and, to the best of our knowledge, for 3D and 2.5D prints. The most relevant attributes need to be specified with the aim to achieve more consistent QA and that QA can be compared between different experiments. The identification of attributes will be helpful in designing objective image quality metrics which in turn can reduce necessity to conduct subjective experiments.

This paper presents both a literature survey and an experimental study towards identifying attributes for QA. It is organized as follows: first, we present a literature study on the attributes for 2D, 3D, and 2.5D prints QA; second, we present a description of our experiment for investigating the attributes used for QA of 2.5D prints. The results and discussion are given afterwards followed by the main conclusions and potential future works.

Background

In everyday life, our visual system experiences massive amount of input information. As stated by Wolfe et al. [6], to tackle this excess input data, a small subset of stimuli is selected by the visual system's attentional mechanisms for extensive processing whereas the rest goes to a limited analysis. In other words, our visual system does reduction of initial input data and works with subset of that input information. Researchers [7-11] mentioned the necessity of defining subset of quality attributes in order to identify and categorise the most relevant quality attributes depending on the application.

Pedersen et al. [5] confirmed experimentally that source of the quality attribute, purpose of use, dimensionality, independence, and attribute size are the most critical aspects to deal with when selecting attributes. Keelan [8] mentioned the following categories of attributes: personal (e.g. preserve a cherished memory), aesthetic (e.g. lighting quality, composition), preferential (e.g. contrast, colour balance, colourfulness (saturation), memory colour reproduction), and artefactual (e.g. graininess, digital artefacts, optical distortions). The preferential attributes are usually visible in images [12]. As an example, some people prefer low contrast images due to details' highlight and shadow enhancement whereas others prefer high contrast images. Another point is that images might be equally perceived in terms of quality even though they have considerable appearance variations in the preferential attributes [8].

Attributes for 2D print quality assessment

There are two options to select attributes: either to consider attributes separately or as a combination of them. For instance, Sawyer [13] examined the combined impact of sharpness and graininess on image quality perception. Field [14] proposed four appearance features for 2D colour printing quality: aesthetics, technical excellence, conformance to specifications, and permanence. Pedersen et al. [5] investigated the most important image quality attributes for 2D colour prints which are lightness, contrast, colour, sharpness, and artefacts. Engeldrum [15] stated that lightness, colourfulness, and sharpness are the perceptual image quality attributes in a 2D context. Dalal et al. [10] presented high level image quality attributes for 2D hardcopy prints such as colour rendition, effective tone levels, process colour gamut, gloss uniformity, effective resolution, macro uniformity, micro uniformity, adjacency, text quality, and line quality.

Attributes for 3D print quality assessment

According to Fleming [16], our visual system captures the whole surface as it is and looks for material parameters' variations among similar samples in terms of easily measured appearance properties such as size, contrast, and distinctness of, for example, highlights.

Urban et al. [17] conducted a visual experiment with 3D printed materials and their equivalent computer simulated versions to provide a device independent standard for 3D printing systems. Their work focused on translucency reproduction and they obtained perceptually and physically meaningful redefinition of the A parameter (i.e. α channel) in 3D file format. An α channel creates overlays of transparency [18]. Brunton et al. [19]

fabricated 3D prints using their proposed 3D printing pipeline for spatially varying colour and translucency.

Additionally, Gigilashvili et al. [20] used real physical 3D objects (which were moulded, not 3D printed) and performed both tactile (i.e. by touch) and visual evaluations of material properties. Based on their conclusions, shape, surface coarseness, and material composition are important visual attributes to consider along with gloss, translucency, and opacity for material appearance assessment. According to them, it is possible to pool a list of attributes to consider in the experiment. If there are same shaped objects, then the same translucency perception would be expected through surface coarseness and material dye composition.

According to Bar et al. [21], curved or sharp prints are also interesting to consider during prints preparation as humans prefer curved visual objects. They explained that sharp angles activate feeling of threat, and therefore, people might dislike objects with sharp angles.

Attributes for 2.5D print quality assessment

Colour is associated as a primary visual attribute in 2.5D prints [22]. In addition, gloss is an important attribute and perceived gloss can be affected by ink type, ink deposition time, halftoning screening, colour separation, print swath size, curing time, to name a few [23]. Parraman et al. [23] described that the relationship between roughness and gloss has been investigated in the last few decades. They stated that the two attributes, roughness and gloss, depend on colour and the interaction between these three (roughness, colour, and gloss) is still undefined in terms of appearance perception.

There are several active terms that are used in the studies involving 2.5D prints: roughness [22, 24-30], coarseness [31], bumpiness [24, 30], texture [22, 24-32], texture height [24, 32], topography [22], and surface relief [22, 25-32]. Sharpness was mentioned in Baar et al. [27] and Wang et al. [31] works in a 2.5D context. In addition, Baar et al. [24] stated that it is important to have measurable attributes (e.g. gloss, roughness, etc.) for accurate perceptual reproductions.

Experiment

From our literature survey above, we concluded that there is no study that clearly identifies attributes relevant for QA of 2.5D prints. To address this issue, we designed an experiment to collect elaborate information from observers judging the quality of 2.5D prints.

The experiment was conducted in a dark room with a light booth cabinet (Verivide CAC 60-5) under D65 illumination. The illumination in the viewing booth was 1353 lux.

Fifteen 2D images were reproduced from Pixabay (copyleft web site to share media). The images in our dataset were selected in the way that they cover a wide range of image quality aspects such as memory colours (sky blue, grass green, skin tone colour), large area of the same colour, sharp objects, texts, neutral grey, and various levels of colourfulness and spatial information [33]. Also, the images have different content, from natural images to signs, representing a wide variety of content that can be printed using 2.5D. The rendering from Canon Touchstone software was used to iteratively design a height map for the 15 images. As a result, 2.5D images are RGB plus height maps. We employed five sets of quality variations: naturalness (natural elevation, unnatural elevation, natural surface roughness), design flaws (edge colour of background, edge colour of object, black edges), printer mode (Alto (i.e. opaque elevation) and Brila (i.e. varnish elevation) effects), maximum height variations (1 mm, 0.5 mm, 0.25 mm), and one group we named as ‘different’ which consists of noise (Gaussian, 3.5%), gamut reduction (US newsprint (SNAP 2007)), and unnatural elevation (produced by CrazyBump software [34]). Figure 1 demonstrates 2.5D images at random angles, rotated, and zoomed for illustration purpose. Fifteen 2.5D images were printed each with three instances (except three images with two instances) with different quality variations resulting in a total of forty-two 2.5D prints. They were fabricated by a professional printing manufacturer (5 x 8 cm, elevation ≤ 1 mm, 446x451 dpi, substrate is alupanel made of aluminium composite materials with 3mm thickness) through the Canon Arizona series 2.5D printer.

Figure 1. *The 2.5D images at random angles, rotated, and zoomed*

The consent of being recorded was obtained before starting the experiment from the observers. The 2.5D prints were presented in random order for each observer to reduce bias and sequential effects. The observers adapted to the illumination for around two to three minutes. The instruction was as follows: “Please rank given 2.5D prints from the highest to the lowest quality and then please describe quality by your own words”. We asked the observers to keep their position and distance from the prints to the eyes constant during the experiment. They were allowed to move and rotate the prints with given gloves, but not touch the surface of the prints. The observers were not allowed to touch the surface in order to avoid them judging tactility. There was no time restriction.

The reason we instructed the observers to describe quality of 2.5D prints by their own vocabulary is that, as Radun [12] proved, people can explain the basis of their quality judgement when they can use their own words because our surroundings considerably accentuate visual information. Describing quality by your own lexicon is not defined in any standardized protocols. However, we employed such assignment so that the observers can assess quality according to their perception without biasing them to focus on a certain attribute as conventional methods do.

We included reference images in order to find out if observers use the same attributes when they see and do not see the references (i.e. if attributes vary with or without references) during 2.5D prints QA. In the first part of the experiment, the observers ranked and described quality of the 2.5D prints without seeing reference images, followed by 5 minute break. Afterwards, in the second part of the experiment, they repeated the task with 2D reference images shown on a monitor display (23.8 inch EIZO ColorEdge CG248 LCD monitor). The calibration of the display was the following: colour temperature was 6500K, gamma was 2.2, white point luminance level was 80 cd/m^2. Even though we are working with 2.5D reproductions, we showed 2D images as references because all our original images are 2D and printed as 2.5D. Moreover, there are several challenges displaying 2.5D images such as which viewing angle is optimal to capture the rendered 2.5D images and technical challenges to render realistic 2.5D appearance. Also, it is practical to compare physical print with its softcopy version in industry. In addition, in a preliminary experiment it was observed that the participants tend to compare the prints with some imaginary references based on their experience, memory, or knowledge when no references were given. Thus, the imaginary references that the observers relate to can be different than the real references.

The duration was around 56 minutes (33 minutes and 23 minutes on average for without reference and with reference cases, respectively) per observer as recommended in the literature [35] and guideline [36]. We had 15 observers (7 females, 8 males) as it is recommended by ITU [36] and CIE guidelines [37]. Average age was 33 years with a standard deviation of 7.5 years. All observers were tested for visual acuity and colour vision through Snellen chart and Ishihara plates, respectively. Regarding ethnicity, the observers represent a wide range of origins: middle east, European, and Asian. Majority of participants (i.e. 11 people) have technical background such as colour science, computer vision, computer security, colour management, and material science. The reason of having naïve and experienced observers is to mimic potential consumers of 2.5D products. The experiment was conducted in English. Majority of our observers were not native speakers of English. Therefore, this aspect can impact on the observers' performance in the way that their quality judgements might be constrained to a limited set of vocabulary.

Results and discussion

The attributes used by the observers were combined into larger groups with the aim to derive the most used distinct attributes through frequency analysis. We combined vividness sub-attribute into the saturation sub-attribute because, according to Berk et al. [38], one of the saturation levels is vividness based on Inter Society Color Council National Bureau of Standards (ISCC-NBS) lexicon. Colourfulness was included into the saturation sub-attribute according to the classification by Pedersen et al. [39]. Similar to Pedersen et al. [5], saturation and colour were grouped into the colour attribute; sharpness, details, edges, clarity, blurry, and (pixel) resolution were grouped into the sharpness attribute; lightness, darkness, and brightness were grouped into the lightness attribute. Noise [5], halo [39], damage (cracks, holes, dots), dust, and artefacts were grouped into the artefacts attribute. Specular gloss [40], haze [40], sheen [40], shiny (identifies specular gloss and sheen [40]), reflection (specular, diffuse), scattering, and matt were grouped into the gloss attribute. The naturalness attribute contains sub-attributes such as real, unreal, and photoshopped [41]. Also, naturalness and unnaturalness were included into the naturalness attribute. The elevation attribute includes height, 2.5D, elevation, flatness, smoothness, depth, shadow, relief, and related terms for elevation and flatness named as elevation related and flatness related. The main reason of such grouping for the elevation attribute is that elevation causes shadow, relief, and depth appearance and lack of elevation produces flat and smooth appearance. 2.5D is also called as relief [26] or elevated printing [42], and therefore, it is included into the elevation attribute. Texture, roughness, and coarseness were grouped into the texture attribute because texture can cause prints to have rough and coarse surfaces. The sub-attributes distribution may not be unique as some of them can go in more than one group.

Figure 2 illustrates the frequency distribution of the most used distinct attributes for without reference and with reference cases. In total, we derived 11 attribute groups for the without reference (further as case 1 in text) and 12 attribute groups for the with reference (further as case 2 in text) cases. Table 1 presents average, minimum, and maximum number of distinct attributes used per observer and per print for cases 1 and 2.

Colour, sharpness, elevation, lightness, naturalness, texture, gloss, contrast, 3D, artefacts, and shape are the most used distinct attributes for both cases. Size was used few times only in case 2 (omitted from Figure 2).

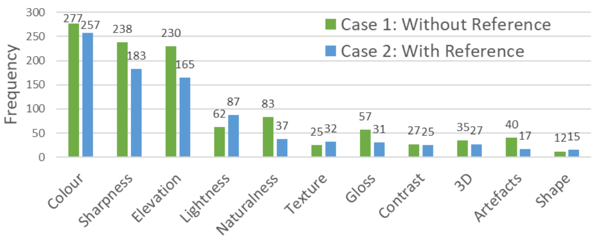

Figure 2. *Frequency distribution of the most used distinct attributes by the observers for QA of 2.5D prints for without and with reference cases*

Table 1. Average, minimum, and maximum number of distinct attributes used per observer and per print for cases 1 and 2

	Per observer		Per print	
	Case 1	Case 2	Case 1	Case 2
Average	7.4	6.9	7.6	7
Minimum	5	4	5	1
Maximum	10	8	10	10

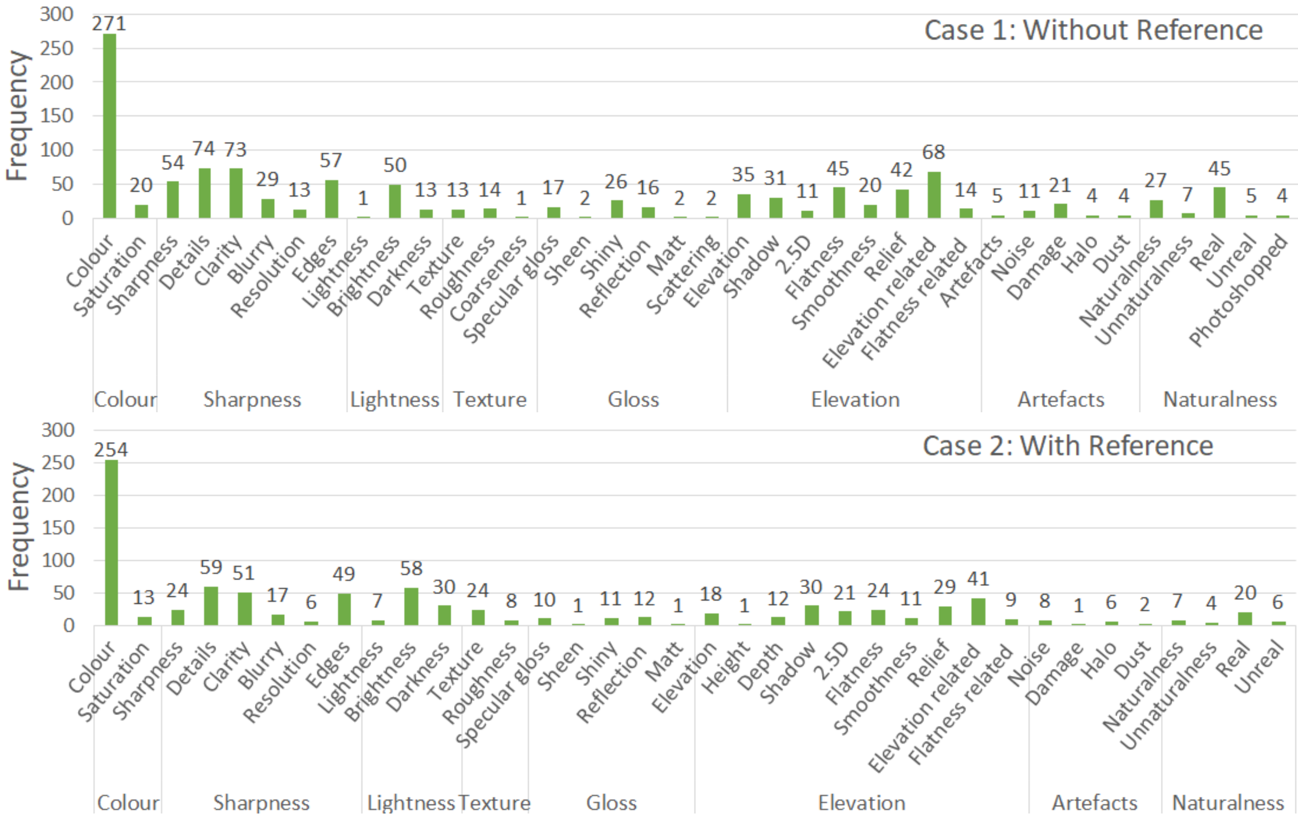

Figure 3. *Frequency distribution of the sub-attributes for without reference case on top and for with reference case on bottom*

The frequency of attributes usage is higher in case 1 than in case 2 for almost all attributes. The possible reason for this might be that the observers have freedom to describe quality when there is no reference image whilst their quality description might be limited when they see the reference image. Colour, sharpness, and elevation were used more frequently than the other attributes in both cases. Moreover, colour and sharpness in both cases are top two attributes which is similar with the results of related but not identical study by Pedersen et al. for the assessment of 2D prints [39]. Overall, all the attributes defined by them for 2D prints (colour, sharpness, lightness, contrast, and artefacts) are present in our results for 2.5D prints.

It is interesting to mention words that the observers used to describe the quality of 2.5D prints. They were expensive, cheap, artistic, aesthetically and visually appealing, occlusions, printer quality, artificial, old, oily, illusion, abstract, clean, substrate, and rigid for case 1. For case 2, the words were expensive, artificial, wet, clean, substrate, aberrations, and rigid. Mostly, observers' words were associated with their memories about specific print's content. For example, one 2.5D print reminded 1980s time for one observer whereas another 2.5D print reminded to another observer animal skin, and the observers ranked the quality based on those memories.

The sub-attributes distribution within the derived attributes deserves attention because it provides information about skewness of the data. Also, for the sub-attributes, it can be helpful to have a balanced number of attributes for later usage in objective QA. The sub-attributes and their frequency level for case 1 can be observed from Figure 3 (top) which contains only those attributes that have at least two sub-attributes. Contrast, shape, and 3D do not have any sub-attributes based on our data. The maximum and the minimum number of sub-attributes were eight for the elevation attribute and two for the colour attribute, respectively. Colour was the most used while lightness and coarseness were the least used.

The sub-attributes distribution for case 2 is visualized in Figure 3 (bottom). The attributes that do not have any sub-attributes are contrast, 3D, shape, and size. Ten was the maximum number of sub-attributes from elevation. Similar to the case 1, colour was the most used. Sheen, matt, height, and damage were the least used.

In terms of inter-observer variability, all observers showed consistent usage of attributes between each other for both cases. For example, for case 1, artefacts were not perceived or at least not mentioned by the observers for the prints with natural elevation. Also, it is reasonable that the prints with Brila effect were not described with matt, elevation, and 3D because Brila effect adds glossiness to the prints and it can be printed only at maximum height of 0.25 mm. It is interesting to note that elevation and 3D among other attributes were not used by the observers for the prints from height set with 0.5 mm. It seems like the observers perceive the prints close to flat when elevation is equal or less than 0.5 mm. For case 2, elevation was not used for prints with Brila effect which is coherent with case 1 to some degree. Surprisingly, naturalness was not used for prints with unnatural and natural elevations. Also, it was not used for prints with noise and reduced gamut. This consistency of attributes usage by the observers can indicate that people tend to use similar attributes for prints with similar content.

Overall, we derived the following observations from the collected data for 2.5D prints QA: aesthetic appearance leads to a higher quality perception (case 1); the observers showed interest to be able to judge tactility, otherwise they felt that the task is complicated (case 1); interestingly, most of the observers perceived depth information from some 2D reference images (case 2); the observers tend to use terminology from their expertise fields (both cases); the observers tend to compare the given print with previous prints they have assessed (both cases); the observers frequently try to interpret the meaning of given prints in terms of content, material type, and purpose (intention) (both cases); experience or previous knowledge about content visualized on the prints directs quality judgements towards a high quality and expectations of how a particular material should look like impact QA (both cases); it was difficult for observers to give an absolute measure of quality (both cases); some observers tend to rank high quality those prints which they think took longer time and more effort to print (both cases); few observers informed that they were confused whether quality was distorted during the printing or it was designed the way it is (case 1); tilting and rotating the prints help to see elevation of 2.5D prints (case 1); some observers found higher elevations and smooth edges appealing because it leads to more detail visibility (case 1); more details lead to a higher quality perception (case 2); however, some observers found higher elevations annoying and that they should negatively correlate with reproduction quality and readability (both cases); also, the observers informed that elevation level depends on context: if object naturally should be elevated, then it was judged as high quality, otherwise as low quality (case 2); most of the time, 0.25 mm elevation was perceived as flat (case 2); shape, scale, and size may affect the QA (both cases); the observers showed tolerance to small artefacts (case 1); noise artefact was always judged towards low quality (case 1); majority of attributes were used to indicate both global and local quality (e.g. artefacts and shadow were used to show local regions while colour was used for the whole surface) (both cases).

To conclude, we propose to consider the most frequently used distinct attributes found in our experiment as a set of relevant attributes for 2.5D prints QA. Further, we propose to select top five the most frequently used distinct attributes (which are the same for both cases) as relevant ones because Engeldrum [15] specified that the observers can perceive at most five attributes at once and Le Moan et al. [43] stated the similar statement that the observers are capable of assessing only limited number of image attributes simultaneously. Moreover, reducing the number of attributes helps to deal with dimensionality issues and to do feasible QA [5]. The dimensionality is one of the four criteria that should be followed in order to validate selected quality attributes used for 2D prints by Pedersen et al. [39]. Other criteria are that quality attributes should consider the whole image quality research area, dependence between quality attributes should be none or low, and overlapping of quality attributes should be close to minimum. These four criteria can also be applied to 2.5D prints with addition that the attributes should cover the needs of various 2.5D application areas such as signage, packaging, décor, paintings, and maps. All our derived attributes cover the image quality field because our observers used a wide range of different attributes. There can be just few overlaps of attributes (i.e. some attributes can be clustered into another attributes). For example, lightness can be clustered into colour. We believe there is a low dependence between derived attributes but it needs to be verified by experimental works which we leave for future work. Similar to the conclusion of Pedersen et al. [44], our proposed relevant attributes for 2.5D prints QA can be used to find relation between subjective and objective QA.

Conclusions and future works

Based on our experimental results, the most used distinct attributes for both with reference and without reference cases are colour, sharpness, elevation, lightness, naturalness, texture, gloss, contrast, 3D, artefacts, and shape. This list includes the same attributes found from the literature for 2.5D prints QA. All attributes except one are the same for both cases. This shows that the observers tend to use the same attributes in both cases. Also, we found that the observers have consistent lexicon regarding QA of 2.5D prints as well as they use similar attributes for similar content prints based on the analysis. According to our results, we can conclude that QA of 2.5D prints is both visual perception based and knowledge based.

The attributes (colour, gloss, relief, texture, and sharpness) selected as relevant for 2.5D prints QA are also present in the studies of QA for 2D and 3D prints based on the literature study. More specifically, colour and sharpness are dominant in 2D, 2.5D, and 3D prints QA. The relief, texture, and gloss are mainly dominant in higher dimensional prints (i.e. 2.5D and 3D).

Our dataset is available online for downloading at https://www.ntnu.edu/web/colourlab/software. It contains reference images that cover relevant content and quality attributes for QA of 2.5D prints. For future work, we plan to analyse derived attributes' associations with respect to low, medium, and high quality for both cases. Both printing quality and design can contribute to the final perception of quality. Therefore, it will be interesting to study which quality attributes are responsible for design and which are responsible for printing quality in the future. In addition, it can be useful to repeat the experiment with the same observers to assess consistency of observers' data over time.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 814158.

References

[1] ISO 12647-2, Graphic technology – Process control for the production of half-tone colour separations, proof and production prints – Part 2: Offset lithographic processes, pp.19, (2004 Nov).

[2] ISO/TS 15311-1, Graphic technology – Print quality requirements for printed matter – Part 1: Measurement methods and reporting schema, pp.32, (2019 Feb).

[3] ISO/TS 15311-2, Graphic technology – Print quality requirements for printed matter – Part 2: Commercial print applications utilizing digital printing technologies, pp. 20, (2018 Oct).

[4] ISO 18621, Image quality evaluation methods for printed matter, (2019).

[5] M. Pedersen, N. Bonnier, J.Y. Hardeberg, F. Albregtsen, "Attributes of image quality for color prints." Journal of Electronic Imaging, 19(1):011016, (2010 Jan).

[6] J. M. Wolfe, T.S. Horowitz, "What attributes guide the deployment of visual attention and how do they do it?" Nature reviews neuroscience, 5(6):495, (2004 Jun).

[7] C. J. Bartleson, "The combined influence of sharpness and graininess on the quality of colour prints." The Journal of Photographic Science, 30(2):33-8, (1982 Mar).

[8] B. Keelan, Handbook of image quality: characterization and prediction, CRC Press, pp.516, (2002 Mar).

[9] K. Natale-Hoffman, E. N. Dalal, R. Rasmussen, M. Sato, Effect of selected image quality attributes on overall preference, in PICS pp. 266-269. (1999).

[10] E. N. Dalal, D. R. Rasmussen, F. Nakaya, P. A. Crean, M. Sato, Evaluating the overall image quality of hardcopy output, in PICS pp. 169-173. (1998 May).

[11] X. Zhang, B. A. Wandell, A spatial extension of CIELAB for digital color image reproduction, in SID international symposium digest of technical papers, Society for Information Display, Vol. 27, pp. 731-734. (1996 May).

[12] J. Radun, Better Images Understanding and Measuring Subjective Image-Quality, University of Helsinki, Institute of Behavioural Sciences, Studies in Psychology, pp.104, (2016 Dec).

[13] J. F. Sawyer, Effect of graininess and sharpness on perceived print quality, in Photographic Image Quality Symposium, pp. 222-231, (1980 Sep).

[14] G. G. Field, Color and its reproduction, Graphic Arts Technical Foundation, (2004).

[15] P. G. Engeldrum, Image quality modeling: Where are we? In PICS, pp. 251-255, (1999 Apr).

[16] R.W. Fleming, "Visual perception of materials and their properties." Vision research, 1;94:62-75, (2014 Jan).

[17] P. Urban, T. M. Tanksale, A. Brunton, B. M. Vu, S. Nakauchi, "Redefining a in rgba: Towards a standard for graphical 3d printing." ACM Transactions on Graphics (TOG), 31;38(3):1-4, (2019 May).

[18] T. Porter, T. Duff, Compositing digital images, in Proceedings of the 11th annual conference on Computer graphics and interactive techniques, pp. 253-259, (1984 Jan).

[19] A. Brunton, C. A. Arikan, T. M. Tanksale, P. Urban, "3D printing spatially varying color and translucency." ACM Transactions on Graphics (TOG), 30;37(4):1-3, (2018 Jul).

[20] D. Gigilashvili, J. B. Thomas, J. Y. Hardeberg, M. Pedersen, Behavioral investigation of visual appearance assessment, in Color and Imaging Conference, Society for Imaging Science and Technology, Vol. 2018, No. 1, pp. 294-299, (2018 Nov).

[21] M. Bar, M. Neta, "Humans prefer curved visual objects." Psychological science. 17(8):645-8, (2006 Aug).

[22] T. P. Van Song, C. Andraud, M. V. Ortiz, Towards spectral prediction of 2.5 D prints for soft-proofing applications, in 2016 Sixth International Conference on Image Processing Theory, Tools and Applications (IPTA), IEEE, pp. 1-6, (2016 Dec).

[23] C. Parraman, M. V. Ortiz, 2.5 D Printing: Bridging the gap between 2D and 3D applications, John Wiley & Sons, (2018 Oct).

[24] T. Baar, S. Samadzadegan, P. Urban, M. V. Ortiz, Interrelation between gloss and texture perception of 2.5 D-printed surfaces, Electronic Imaging Symposium, Society for Imaging Science and Technology, 2016(9):1-6, (2016 Feb).

[25] X. Liu, L. Chen, M. V. Ortiz, J. Ferwerda, J. Allebach, "Characterization of relief printing." In Measuring, Modeling, and Reproducing Material Appearance, International Society for Optics and Photonics, Vol. 9018, p. 90180P, (2014 Mar).

[26] T. Baar, S. Samadzadegan, H. Brettel, P. Urban, M. V. Ortiz, "Printing gloss effects in a 2.5 D system." In Measuring, Modeling, and Reproducing Material Appearance, International Society for Optics and Photonics, Vol. 9018, p. 90180M, (2014 Feb).

[27] T. Baar, M. Olen, C. Parraman, M. V. Ortiz, Woodblock printing as a means for 2.5 D and 3D surface evaluation, AIC 2015, Color and Image, Midterm Meeting of the International Color Association, pp.6, (2015 May).

[28] N. Yan, Assessment, Characterization, and Improvement of Image Quality for Color/2.5 D Printing and Scanned Document, Doctoral dissertation, Purdue University, (2017 May).

[29] M. Page, G. Obein, C. Boust, A. Razet, Adapted modulation transfer function method for characterization and improvement of 3D printed surfaces, Electronic Imaging Symposium, Society for Imaging Science and Technology, 29;2017(8):92-100, (2017 Jan).

[30] T. Baar, H. Brettel, M. V. Ortiz, A survey of 3D image quality metrics for relief print evaluation, in 2013 Colour and Visual Computing Symposium (CVCS), IEEE, pp. 1-6, (2013 Sep).

[31] J. Wang, J. P. Allebach, M. V. Ortiz, Semantically-based 2.5 D texture printing, in 2014 IEEE International Conference on Image Processing (ICIP), IEEE, pp. 2634-2638, (2014 Oct).

[32] W. S. Elkhuizen, This is not a painting: Scanning and printing a painting's appearance, Delft University of Technology, Ph.D. thesis, (2019 Oct).

[33] S. Winkler, "Analysis of public image and video databases for quality assessment." IEEE Journal of Selected Topics in Signal Processing, 6.6: 616-625, (2012 Oct).

[34] R. Clark, CrazyBump, https://www.crazybump.com/, Access: January 2020, (2010).

[35] I. Van Der Linde, U. Rajashekar, A. C. Bovik, and L. K. Cormack, "DOVES: a database of visual eye movements." Spatial vision, 22(2):161–177, ISSN 0169-1015, (2009).

[36] International Telecommunication Union, Methodology for the subjective assessment of the quality of television pictures, Recommendation ITU-R BT, Geneva, (2012).

[37] CIE, Guidelines for the evaluation of gamut mapping algorithms, PUBLICATIONS-COMMISSION INTERNATIONALE DE L' ECLAIRAGE CIE, 153:D8-6, (2003).

[38] T. Berk, L. Brownston, A. Kaufman, "A New Color-Naming System for Graphics Languages." IEEE Computer Graphics and Applications, (3):37-44, (1982 Mar).

[39] M. Pedersen, N. Bonnier, J. Y. Hardeberg, F. Albregtsen, Validation of quality attributes for evaluation of color prints, in Color and Imaging Conference, Society for Imaging Science and Technology, Vol. 2010, No. 1, pp. 74-79, (2010 Jan).

[40] R. S. Hunter, R. W. Harold, The measurement of appearance, Wiley, New York, pp.411, (1987).

[41] T. Virtanen, M. Nuutinen, J. Häkkinen, "Image quality wheel." Journal of Electronic Imaging 28.1, 013015, (2019).

[42] Oce Technologies BV: Project Eiger Elevated Printing, (2017).

[43] S. Le Moan, M. Pedersen, I. Farup, J. Blahová, The influence of short-term memory in subjective image quality assessment, in 2016 IEEE International Conference on Image Processing (ICIP), IEEE, pp. 91-95, (2016 Sep).

[44] M. Pedersen, N. Bonnier, J. Y. Hardeberg, F. Albregtsen, Attributes of a new image quality model for color prints, in Color and Imaging Conference, Society for Imaging Science and Technology, Vol. 2009, No. 1, pp. 204-209, (2009 Jan).