DIRECTIONAL LIGHT OF LED ARRAYS AND ITS INFLUENCE ON SHAPE PERCEPTION

Krüger, J.[1], Schierz, Ch.[2]
[1] Federal Institute for Occupational Safety and Health, Dresden, GERMANY
[2] Technische Universität Ilmenau, Department of Lighting Engineering, Ilmenau, GERMANY
krueger.jan@baua.bund.de

Abstract

Our study shows the extent to which the complexity of the light field has an influence on shape perception. It is hypothesized that more complex light fields are associated with a larger error in shape perception. Due to LED technology and the use of LED arrays, light fields are becoming increasingly complex. From shape-from-shading experiments it is known that the visual system must make assumptions about the light field and the light direction to perceive the form correctly. The results show that complex light fields from LED arrays can lead to a distorted perception of shape, whereas simple directional or diffuse light fields enhance shape perception.

Keywords: shape from shading, LED array, directional light, multi shadows

1 Introduction

In shape perception, three-dimensional structures of objects are transformed into a two-dimensional light pattern on the retina (Gibson, 1979). Subsequently, 3D information needs to be extracted from that image on the retina. For that purpose, a multitude of information sources are available to the visual system:

- shading
- cast shadows
- outer contours of the object
- texture and surface quality (e.g. reflection properties)
- object movement
- disparity from stereo perception
- direction of light and nature of the light source

Despite the variety of shape stimuli, the perception of shapes is often about an under-determined task of perception. The reason for that is the fact that the above mentioned stimuli may be ambiguous. Different geometric structures, for example, may generate the same optical pattern (Todd, 2004). Khang (2007) points out that such under-determination may be dissolved by additional indicators, such as the ones listed above. Should no information for dissolving such ambiguities be available to the visual system, assumptions must be made. First of all, such assumptions relate to the structure of the light field and the properties of the light source (e.g., intensity, direction, spectral composition, level of diffusion, the number of light sources). Investigations by Kleffner (1992) show that the following assumptions are made by the visual system as long as the scene does not contain any unambiguous information on the light field:

- a single light source illuminates the entire scene (single light source constraint)
- the light shines from above (light from above constraint)

Concerning the type of light source adopted by the visual system various investigations assume either a directional (Kleffner and Ramachandran, 1992), a diffuse (Langer and Bülthoff, 2000) or a mixed light source involving a combination of direct and diffuse lighting which is combined according to a certain weighting (Schofield et al., 2011). Koenderink (2007) also raises the claim that, in shape perception, observers would have an idea of the physical light field.

These assumptions are frequently violated in real illumination scenes. Especially when applying LED light sources, complex light fields may emerge due to the characteristic properties, such as the small size of the source or the focused directionality of the light (Knoop, 2011). In reality, the requirements of lighting can rarely be met by lamps of a single high-power LED; for that reason, there is the trend towards the application of LED arrays in the development of LED lamp design (Xue et al., 2016). Thereby, LED arrays may be made up by a variety of locally separated points of lighting that result in directional light. These light sources generate an unusual light field – due to the large light-emitting surface, the impression of a diffuse light source arises, which is actually composed of many single directional light bundles from the individual light points and which may cause multiple shadowing. Should, additionally, the secondary light field be considered, which emerges out of interreflections on the object and with its environment, the light field becomes many times more sophisticated. Moreover, arguments may be raised from an evolutionary perspective that natural light fields, such as sunlight, show a rather uniform structure or a divergent one in the case of candlelight or fire (van Doorn et al., 2011). Hence, the investigations at hand shall serve the purpose to examine for the first time how the visual system copes with this complexity in real light scenes and it is considered in shape perception.

2 Method

In a laboratory test, the impact of a complex LED light field on shape perception in a real lighting situation was to be investigated. Thereby, the lighting conditions included three differently lit scenes (direct, diffuse, direct multiple shadows). A characterisation of the lighting scenes with luminance images of the evaluation object is summarised in Table 1. In selecting the light direction, care was taken that the lighting would generate, apart from shading, also attached shadows on the object surface. The figures in Table 1 show – depending on the light scene – multiple shadows or single shadows on the object surface. In all light scenes, the average lighting density on the object surface was 70-80 cd/m². No glare and no disturbing reflections occurred to the observer.

49 subjects, aged 20-35, took part in the test. Each test person evaluated the same object in two different lighting situations. In order to avoid memory effects, the object was turned by 90 degrees in the second test run. The participants were told they would evaluate a different object in the second test run. This resulted in a balanced repeated measurement plan with two repetitions.

According to Koenderink (2001), the following three methods have proved to be practical for gathering shape perception: gauge figure task, pairwise depth-comparison task, cross-section replica task. The idea behind these methods is to split up a 3D structure into many small parts, whereas each individual part is described by a certain feature (e.g., depth, orientation) (Todd, 2004). Subsequently, subjectively perceived surface reliefs can be calculated from the data gathered. A comparison of the various methods resulted in a similarly high quality of results for all methods (Koenderink et al., 2001). According to the participants' evaluations, the gauge figure task appeared to be the most natural and simple task; hence, this method was chosen to be applied in our test. Another benefit of the gauge figure task is its high test-retest reliability as well as its proven scope of applications in most varied shape evaluating tasks (Norman et al., 2006). The gauge figure task was originally developed by Koenderink (1992) and was implemented by Wijntjes (2012) in a MATLAB program, which was applied for the purpose of our tests. For its application in real lighting scenes, the gauge figure task was slightly modified (Krüger, 2013). An outline of the body to be evaluated was presented to the test persons on a screen placed underneath the real object (figure 1). The gauge figure task was to be performed on that silhouette (black square in figure 1). Apart from the object's outline, the silhouette included no other visual information on the shape of the object (no shadings, edges, textures).

It was the subjects' task to adjust a measuring figure in 187 reference points in their orientation within the silhouette. The orientation of the measuring figure was expected to approximately correspond with the surface inclination of the object in its real lighting situation.

The participants needed to evaluate the shape by means of changing their view between the object and the screen.

In addition to evaluating the shape, the subjectively experienced strain was recorded using a visual analogue scale created by Eilers (1986). The scale ranged across seven scale anchoring points (from extraordinarily strenuous to hardly strenuous). During their evaluation task, the subjects stayed inside the test room. Thus, there was the possibility for the subjects to retrace the position and number of lamps in a light scene to make assumptions of the prevailing light field.

In designing the 3d object to be evaluated, care was taken to let the object have both convex and concave areas as well as saddle points and inflection points. The object was designed in CATIA V5R16 as a CAD model and subsequently printed out on a 3D printer. This approach offered the benefit of having the CAD model available as a reference model of the true surface data for comparison with the subjects' results. The dimensions of the object were 18x18x18 cm and were presented at a distance of 1.5 m from the observer. It had nearly Lambertian reflectance properties. Thereby, the viewing position was fixed by a chin rest.

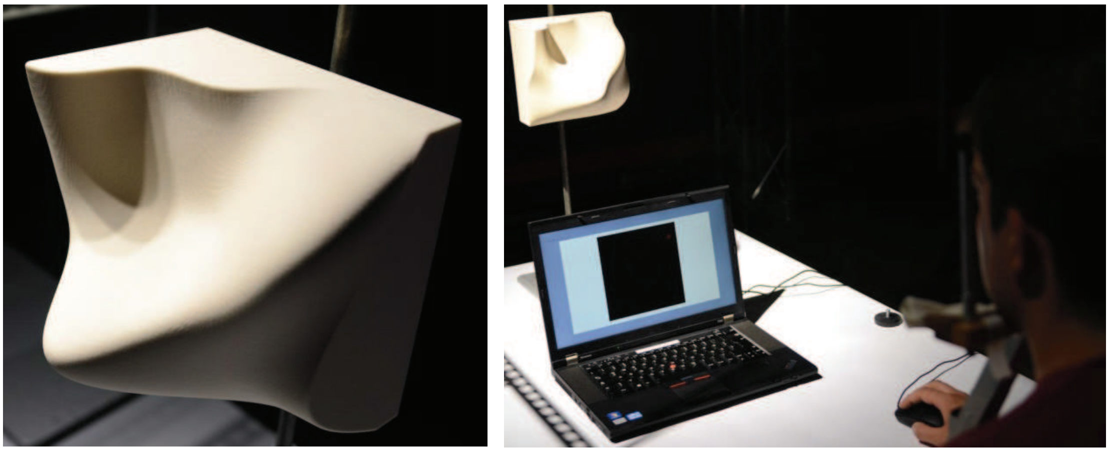


Figure 1 – 3d object (left), schematic illustration of the experimental design (right)

3 Results

In order to be able to compare the similarity of the subjectively perceived object shapes with the true data of the CAD model, the root-mean-square error (RMSE) and the determination coefficient R^2 were calculated. The RMSE as well as the R^2 represent measurements for the dissimilarity or similarity between object shapes perceived and the model. A small RMSE indicates high similarity, whereas a high RMSE describes heavy deviations from the object shape; contrasted by a large determination coefficient indicating high similarity. For considering individual differences in depth scaling, Koenderink (2001) and Todd (2004) suggest to apply an affine transformation when calculating the determination coefficient. These recommendations have been followed in our calculation.

Generalised estimation equations were applied to the statistical analysis (GEE model in SPSS 23). The model contained the RMSE as a dependent variable as well as the lighting, the run number and the object rotation as factors. In addition to that, the subjectively experienced strain was adopted to the model as a covariate.

The statistical analyses yielded significant effects for the lighting and for the run number. The object rotation as well as the subjectively experienced strain show no substantial differences. Although the participants had been familiarised with the shape evaluation method prior to the test runs, the subsequent two test runs revealed a significant learning effect. Beyond that, there were significant differences in the object shapes perceived between the light scene with a complex light field of the LED array (multiple shadows) and the direct lighting situation ($p=0.001$) as well as the diffuse lighting situation ($p=0.01$). No difference in shape perception became apparent between direct and diffuse lighting ($p=0.717$). Table 2 illustrates the results.

Table 1 – Characterisation of the light scenes

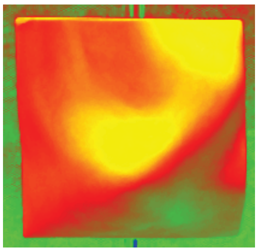
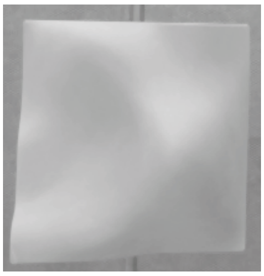
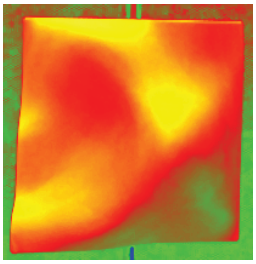
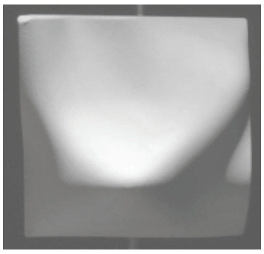
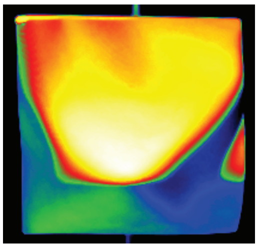
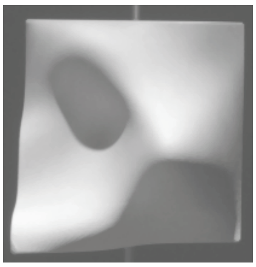
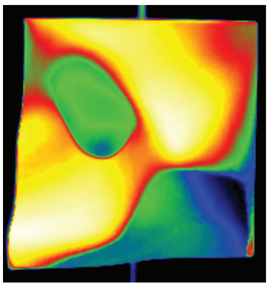
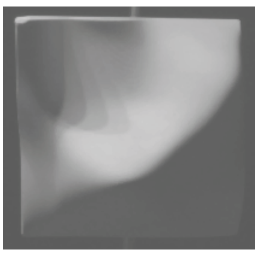
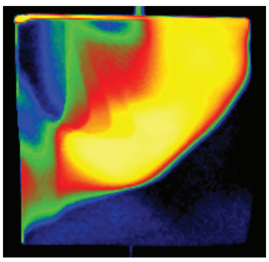
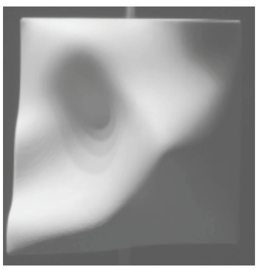
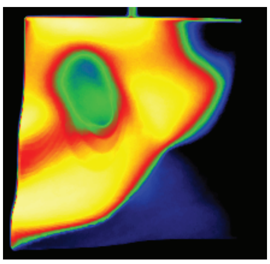
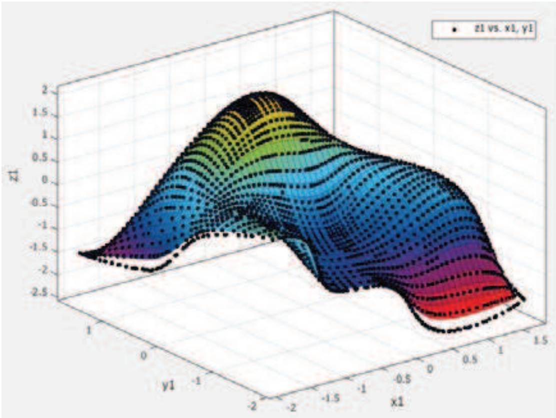
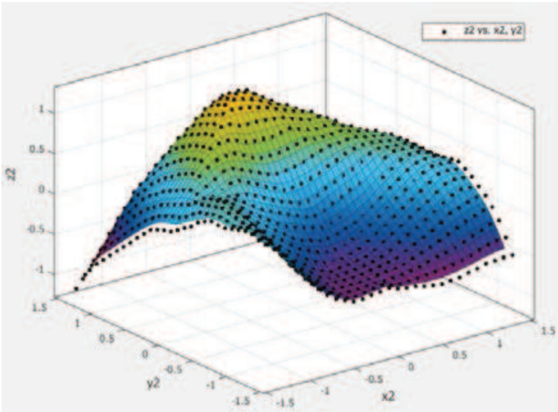
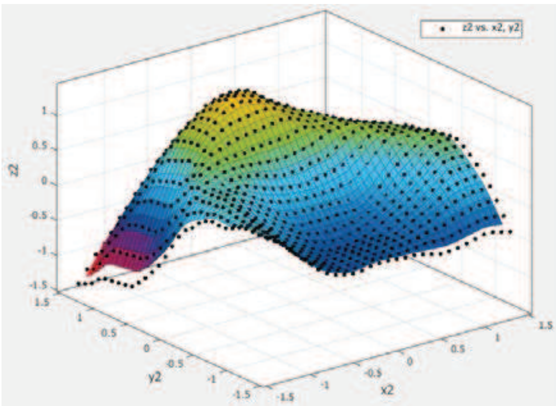
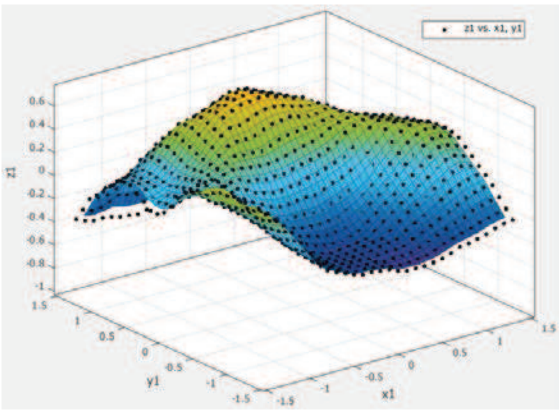
Scene	Picture	Luminance image	Description	E_v in lx	$\frac{E_z}{E_h}$
Diffuse			Diffuse lighting from fluorescent tubes	305	0,37
Diffuse			Object rotated by 90°		
Direct			Directional light from a separate LED point source	155	0,16
Direct			Object rotated by 90°		
Direct multiple shadows			Directional light from five separated LED point sources	188	0,17
Direct multiple shadows			Object rotated by 90°		

Table 2 – Subjectively perceived object shapes, depending on the light scene

Scene	Subjectively perceived object shape, averaged	RMSE Mean	R^2 Mean
CAD Model		0	1
Diffuse		0,39	0,75
Direct		0,4	0,76
Direct multiple shadows		0,49	0,63

4 Discussion

The result that shape perception did not change by rotating the object is interesting. The shading pattern produced from object rotation by 90° could be related to a modification of the light direction by 90° (provided that the object has Lambertian reflectance properties). If one compares these test results to those obtained by other research groups, they will be contradictory to them. A different shading pattern will appear by rotating the object. This pattern is also reflected in the luminance images of Table 1. Nonetheless, the new shading pattern in this test did not lead to another shape perception. Investigations by Nefs (2005) or Koenderink (1996a, 1996b) showed, however, changes in the object form perceived depending on the lighting direction. Possible reasoning for such discrepancies may be found in our experimental design. In the investigations by Nefs and Koenderink, the shape perception was examined by way of two-dimensional images. Koenderink describes these conditions as pictorial space. Another special difference in the test setups is due to the fact that the images used in the quoted studies contained no information about the light field. As described in the introductory section, the subjects were expected to make assumptions on the light field and the changes in light direction in order to be able to solve the underdetermined issue of shape perception. However, the tests described here were performed under full-cue conditions. The participants had the opportunity to build an idea of the light field, as the lamps, their inclination and arrangement was visible to them. Consequently, the visual system did not need to make any assumptions regarding the light field, which reduced the under-determination of the shape perception task and which resulted in shape consistency, which seems to be invariant from the direction of light incidence or object rotation, respectively. These assumptions are supported by investigations performed by Christou (1997) which found out that shape consistency improved with changing the lighting direction if, additionally to the shadings, interreflections and texture were added to the object.

The previous section demonstrates the peculiarity of the test design. Shape-from-shading experiments often consider two-dimensional cues generated by ray-tracing programmes. Thereby, marginal conditions, such as uniform light fields of parallel light beams or ideal Lambert emitters, are defined (van Doorn et al., 2011). Moreover, multiple reflections from the surrounding environment frequently remain unconsidered. Contrary to that, the impact of real light scenes was investigated in the test at hand.

Moreover, the test results demonstrate deterioration in shape perception in a complex light field of directional light from multiple LED spotlight sources. Thereby, this deterioration is not due to higher strain. This result is surprising as directional light enhances shape perception in general. The reason for that effect may be assumed to be in the light field of the LED arrays being too complex for the visual system. It may be assumed that the visual system is trying to explain the issue of shape perception by way of a uniform light field (van Doorn et al., 2011) and, thereby, errors in shape perception occur. The introduction made reference to studies ((Kleffner and Ramachandran, 1992), (Langer and Bülthoff, 2000),(Schofield et al., 2011)), which show that the visual system assumes a direct or diffuse default light source under certain conditions. Possibly that is why better shape evaluations were obtained in the direct or diffuse lighting situation. In addition, this assumption would explain why no significant differences occurred between direct and diffuse lighting.

Also of interest are at this point the findings made by Kleffner, who noted that, in conflicts between different shape cues, depth perception will be reduced. Kleffner was able to show that congruent shape information triggered a stronger depth effect than incongruent ones. A similar effect can be interpreted qualitatively into the graphs in Table 2. A reduced object depth is apparent there in the complex light field.

The results obtained from that experiment have special importance to activities that require shapes to be perceived as true to reality as possible. Such knowledge may be of relevance to the modelling of faces, for example. Juslen and Tenner (2005) point to the fact that the appearance and interpretability of facial features may have an influence in interpersonal relationships and on team work in an office context. Modelling will also have special importance during video conferences (Boyce et al., 1999). Furthermore, a current CIE Report on the topic of "Lighting Quality Measures for Interior Lighting with LED Lighting Systems" (CIE 205:2013, 2013) draws attention to the fact that an evaluation criterion is required for the modelling of faces. The method presented here for gathering the subjectively perceived object shape might be used for comparing and contrasting several modelling indices to each other. In addition to shape perception by the observer, such application would have to take into account the light quality sensed by the illuminated person. Such an approach could supplement or objectify questionnaire-based surveys (e.g., (Veitch et al., 1996),(Boyce et al., 1999)) regarding modelling.

For practical lighting design, it may be of advantage to make available to the visual system a simple light field in order to support shape perception that is true to reality.

References

BOYCE, P. R., MILLER, N. J. & WILWOL, K. (1999) Lighting for good facial modeling. *IESNA annual conference technical papers.* Illuminating Engineering Society of North America.

CHRISTOU, C. G. & KOENDERINK, J. J. (1997) Light Source Dependence in Shape from Shading. *Vision Research,* 37, 1441-1449.

CIE 205:2013 (2013) Review of Lighting Quality Measures for Interior Lighting with LED Lighting Systems. Wien, International Commission on Illumination.

EILERS, K., NACHREINER, F. & HÄNECKE, K. (1986) Entwicklung und Überprüfung einer Skala zur Erfassung subjektiv erlebter Anstrengung. *Z. für ArbWiss,* Jg. 40, 215-224.

GIBSON, J. J. (1979) *The ecological approach to visual perception*, Houghton Mifflin.

JUSLEN, H. & TENNER, A. (2005) Mechanisms involved in enhancing human performance by changing the lighting in the industrial workplace. *International Journal of Industrial Ergonomics,* 35, 843-855.

KHANG, B. G., KOENDERINK, J. J. & KAPPERS, A. M. (2007) Shape from shading from images rendered with various surface types and light fields. *Perception,* 36, 1191-213.

KLEFFNER, D. A. & RAMACHANDRAN, V. S. (1992) On the perception of shape from shading. *Perception & Psychophysics,* 52, 18-36.

KNOOP, M. (2011) Lighting Quality Measures for Interior Lighting with LED Lighting Systems. IN CIE (Ed.) 197:2011 ed. Sun City/South Africa, CIE Central Bureau.

KOENDERINK, J., J., VAN DOORN, A., J. & KAPPERS, A. M. L. (2001) Ambiguity and the 'mental eye' in pictorial relief. *Perception,* 30, 431-448.

KOENDERINK, J. J., PONT, S. C., VAN DOORN, A. J., KAPPERS, A. M. & TODD, J. T. (2007) The visual light field. *Perception,* 36, 1595-610.

KOENDERINK, J. J., VAN DOORN, A. J., CHRISTOU, C. & LAPPIN, J. S. (1996a) Perturbation Study of Shading in Pictures. *Perception,* 25, 1009-1026.

KOENDERINK, J. J., VAN DOORN, A. J., CHRISTOU, C. & LAPPIN, J. S. (1996b) Shape Constancy in Pictorial Relief. *Perception,* 25, 155-164.

KOENDERINK, J. J., VAN DOORN, A. J. & KAPPERS, A. M. L. (1992) Surface perception in pictures. *Perception & Psychophysics,* 52, 487-496.

KRÜGER, J. (2013) Untersuchungsansatz zur Feststellung der Auswirkungen von Mehrfachschatten auf die Formwahrnehmung. *11. Forum für den lichttechnischen Nachwuchs - 27. bis 29.09.2013 Dörnfeld/Ilm.* Technische Universität Ilmenau - Fachgebiet Lichttechnik; LiTG.

LANGER, M. S. & BÜLTHOFF, H. H. (2000) Depth discrimination from shading under diffuse lighting. *Perception,* 29, 649-660.

NEFS, H. T., KOENDERINK, J., J. & KAPPERS, A. M. L. (2005) The influence of illumination direction on the pictorial reliefs of lambertian surfaces. *Perception,* 34, 275-287.

NORMAN, J. F., TODD, J. T., NORMAN, H. F., CLAYTON, A. M. & MCBRIDE, T. R. (2006) Visual discrimination of local surface structure: Slant, tilt and curvedness. *Vision*

Research, 46, 1057-1069.

SCHOFIELD, A. J., ROCK, P. B. & GEORGESON, M. A. (2011) Sun and sky: Does human vision assume a mixture of point and diffuse illumination when interpreting shape-from-shading? *Vision Research,* 51, 2317-2330.

TODD, J. T. (2004) The visual perception of 3D shape. *Trends in Cognitive Sciences,* 8, 115-121.

VAN DOORN, A. J., KOENDERINK, J. J. & WAGEMANS, J. (2011) Light fields and shape from shading. *Journal of Vision,* 11(3), 1-21.

VEITCH, J. A., MILLER, N., MCKAY, H. & JONES, C. (1996) Lighting System Effects on Judged Lighting Quality and Facial Appearance. *Annual Conference of the Illuminating Engineering Society of North America.* Cleveland.

WIJNTJES, M. W. A. (2012) Probing pictorial relief: from experimental design to surface reconstruction. *Behavior Research Methods,* 44, 135-143.

XUE, T., SU, C., FENG, Z., ZHANG, C. & WANG, W. (2016) Optimized lens design for small angle uniform illumination from an extended source. *Lighting Research and Technology,* 48, 376-383.