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Approach to determine the impact of multi-shadows on shape perception

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1. Introduction

Norden (Norden, 1933) points out a fascinating feature of cast shadows, which is gaining importance for LED lighting. Cast shadows are able to separate the components from which incident light is build up (p. 12). Only if a shadow casting object, is brought into the light field the light components will manifest themselves by shadow contrast, luminance gradient, expansion and number of cast shadows. In the case of directed LED lighting this phenomenon becomes apparent. Due to the spatial arrangement of the LEDs in an array, multi-shadows can occur.(Yagmur and Öztürk, 2011;Kuo et al., 2011;Wu et al., 2011). Norden explains further that this phenomenon of separation is interesting, because the human eye is not able to distinguish whether the light is coming from one single light source, or a variety of smaller light sources, when one is looking at an illuminated area. Even a difference between diffuse and direct lighting is imperceptible for the human eye (p.11). This is probably the reason why no attention is devoted to this attribute in lighting design for workplaces. Not even photometers or luminance meters are able to detect the composition of light.
For this reason the importance in detecting the composition of light will be investigated for the impact of multi-shadows on shape perception. It is hypothesized that multi-shadows change the perceived shape of an object due to their unnatural cast shadow.

To make conclusions about the shape of the object, the visual system analyzes the following paths of information: binocularity, motion of the object, cast shadows, texture, silhouette and shading (Todd, 2004). The appearance of multi-shadows, influences two of these paths of information in a direct way; cast shadows and shading. Therefore it could be derived that multi-shadows affect the perception of three-dimensional objects. Experiments by Castiello and Norman give further insights into the relationship between shadows and shape.

Castiello (Castiello, 2001) conducted experiments in which subjects had to recognise objects presented on a display. The objects had either consistent or inconsistent shading or cast shadows. For example objects were shown that casted shadows that could not correlate to the original object. Other objects exhibited shading that was incongruent with the cast shadow. The required recognition time was recorded in response to inconsistency of shadow. Castiello's results reveal longer recognition times for objects with inconsistent shadows.

Further evidence for the hypothesis that unnatural cast shadows affect object recognition, can be obtained from the experiments by Norman et al. (Norman et al., 2009). In their experiments cast shadows on curved surfaces had to be assigned to a corresponding object. The aim of the study was to find out the degree of distortion up to which the assignment to the corresponding object would be unaffected (p.1). Norman discovered that cast shadows on saddle shaped surfaces could not be assigned unambiguously.

These findings show that cast shadows play an important role in object recognition. In the case of multi-shadows, it could be derived that unnatural cast shadows and shading have a negative impact on perception of objects. To verify this hypothesis, the following method from the field of “computer vision” (Todd et al., 1996) was adapted for use under real lighting conditions.

2. Method

How can shape perception be investigated under real lighting conditions? Mamassian et al. (Mamassian and Kersten, 1996) discusses that local judgments about depth or orientation of small areas of the surface are appropriate to describe object shape. Todd et al. and Mamassian et al. applied similar approaches and tested their methods on smoothly curved surfaces. Todd et al. presented photographs of sculptures. And Mamassian presented rendered pictures of virtual objects under varying lighting conditions on a computer screen. Both approaches have in common that the observer has the task to adjust a small gauge figure, in slant and tilt, according to the orientation of the object surface on an evaluation point. The assessments of the observer were used to reconstruct the perceived object surface afterwards. In other words, an object was divided into a matrix of small surface elements. Every element of the surface had to be characterized in its 3D structure by slant and tilt. A limitation of these approaches is the utilization of photography or virtual objects presented on a display. Todd describes that the application of these methods for full-cue-conditions still has to be examined. For this reason the method was combined with the concept of Hayward (Hayward, 1998). In the studies of Hayward, observers had to assign silhouettes to a corresponding object.

For the purpose of our experiment the two approaches (Todd / Mamassian + Hayward) were combined, in a way that observers were shown a real object under full-cue-conditions and concurrently a silhouette of this object on a computer screen. The participants were asked to make their judgments of surface orientation by the silhouette of the real object, displayed on the computer (Figure 1).

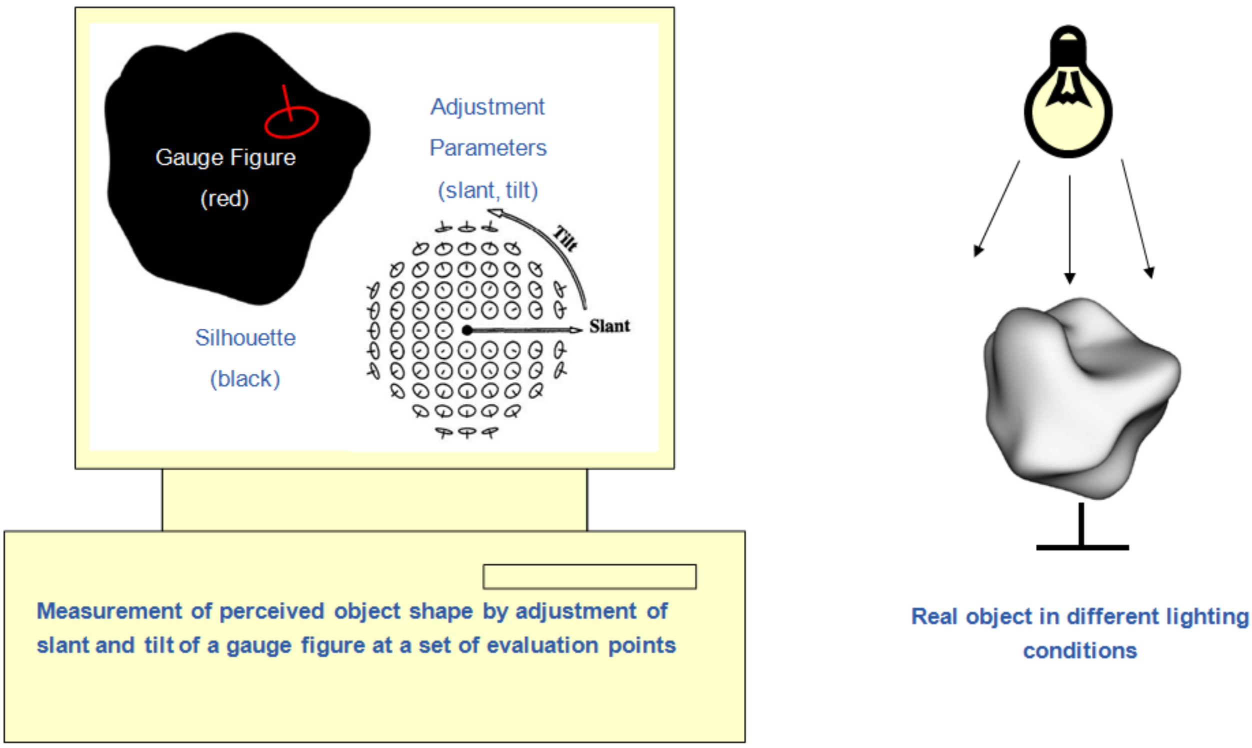


Figure 1: Schematic illustration of the method

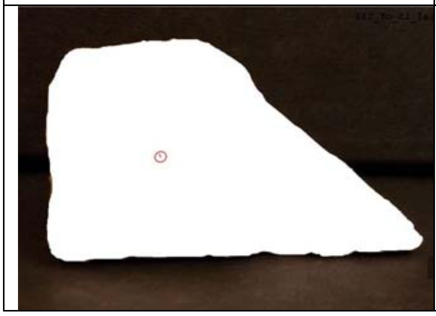
3. Study design:

Figure 2: Study design

Six participants were sitting in front of a complex shaped three dimensional object, with diffuse reflection properties. The objects were designed in an abstract manner, to minimize interfering associations with familiar object shapes. Lighting conditions were changed between the groups. For determination of perceived object shape, the (MATLAB/Psychtool) m-Files generated by Wijntjes (Wijntjes, 2012) were used. The silhouette of the test object was displayed on a laptop (Figure 2). The stimuli (Table 1) contained no other information about object shape but the silhouette (no shading, no edges and no textures).

For 112 evaluation points on the silhouette, the observers were asked to adjust a gauge figure in slant and tilt, in the way that it matched the orientation of the object surface presented in the real lighting condition. The observers had to make their judgments by constantly switching their view between object and silhouette. The adjusted angles were saved and processed into depth, by the calculation methods of Todd (Todd et al., 1996). After completion of the assessment for every observer, a file was generated with X,Y,Z coordinates describing the perceived object structure. X,Y points described the position of the evaluation point on the silhouette and the Z coordinate described the perceived depth at this point.

Table 1: Test object

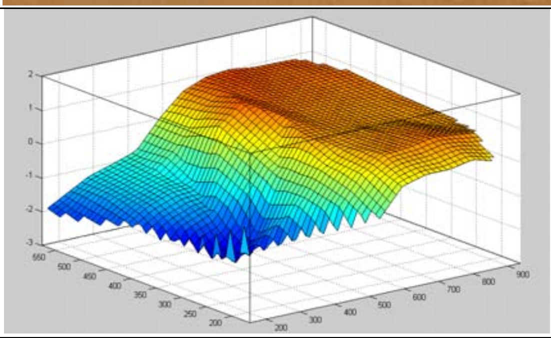
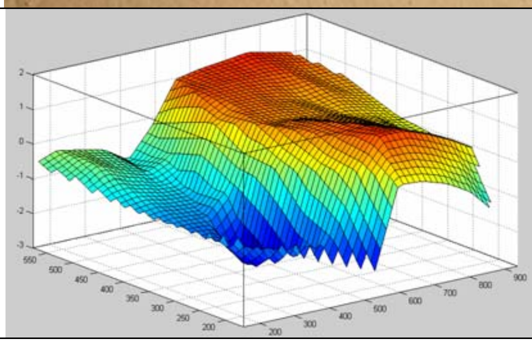
Silhouette	Diffuse lighting condition	Direct lighting condition
		

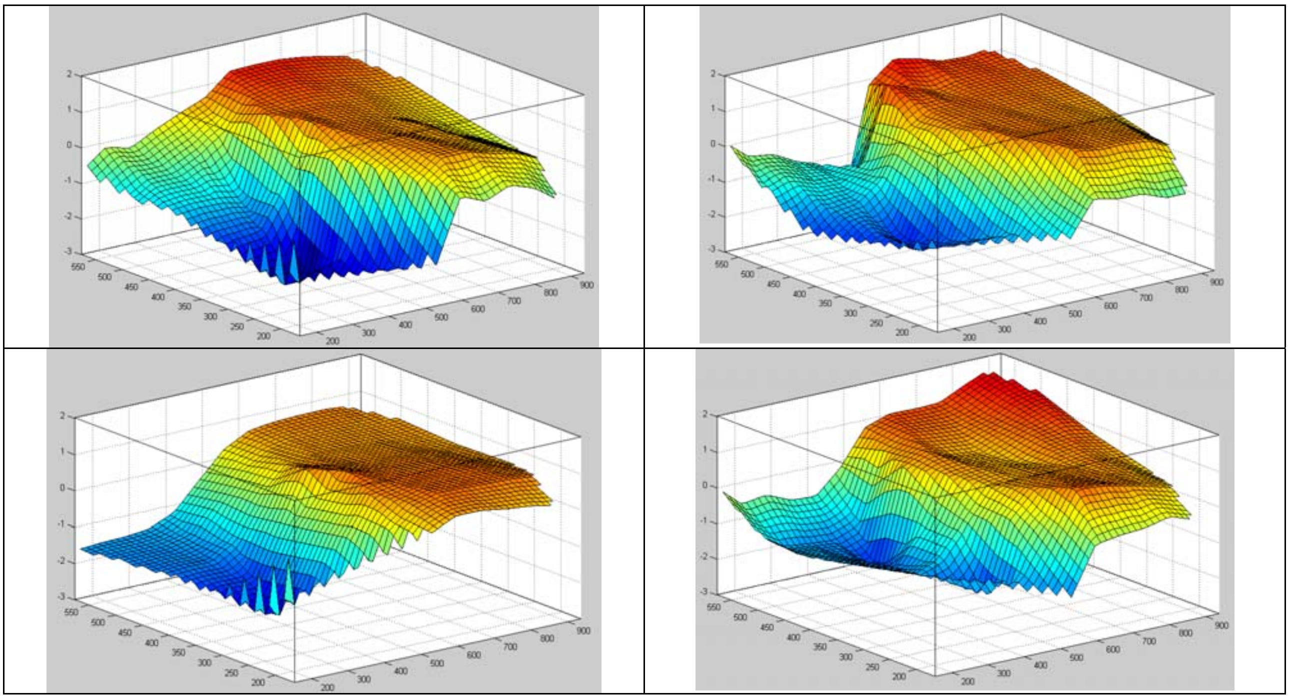
To obtain a pronounced measuring effect, contrary lighting conditions were compared. In the diffuse lighting condition, general lighting from fluorescent lamps was turned on. In the direct lighting condition, the object was illuminated from the side by a halogen desk lamp. Daylight was excluded in both conditions. The aim of this experiment was proof-of-concept therefore no additional photometric measurements were conducted.

4. Results

For the purpose of better comparison between the observers, the reconstructed surfaces were standardized by Z-transformation. The MATLAB-Curve-Fitting-Tool was used to reconstruct the perceived surfaces from the X,Y,Z-coordinates obtained from every participant. Table 2 shows the fitted surfaces (left column diffuse lighting, right column direct lighting). From the table it can be seen that the surfaces computed for direct lighting show a pronounced drop of depth at the edges. From the comparison it could be concluded that objects under direct lighting are perceived more plastically with a higher depth gradient.

Table 2: Qualitative comparison of reconstructed surfaces

Diffuse lighting condition	Direct lighting condition
	
	



To make sure that observers of each lighting condition have nearly the same impression of the shape, surfaces were checked for correlation. Table 3 and 4 show more consistent impressions between observers of the direct lighting condition. Therefore different observers have the same perception of object shape under direct lighting. For direct lighting an overall correlation of 0,9 was calculated, in contrast to 0,8 for diffuse lighting. From other experiments (unpublished) with less curved objects (flatter objects) it was found that diffuse lighting can lead to misperception of object shape, while direct lighting resulted in high correlation of perceived shape between observers.

Table 3: Pearson correlation between observers for diffuse lighting conditions

Observer 1 – Observer 2	0,841**
Observer 1 – Observer 3	0,709**
Observer 2 – Observer 3	0,944**
Overall correlation	**0,831**

Table 4: Pearson correlation between observers for direct lighting conditions

Observer 4 – Observer 5	0,898**
Observer 4 – Observer 6	0,917**
Observer 5 – Observer 6	0,916**
Overall correlation	**0,910**

To support the findings from the qualitative analysis, gradient vectors at the evaluation points were computed. The gradient vector describes direction and magnitude of the surface slope. Figure 3 shows a contour plot for observer 4. Areas of same color mark regions of same depth. Additionally, the figure shows the gradient vectors marked as blue arrows. A comparison of the means between the two lighting conditions exhibited higher magnitudes of the gradient vector for direct lighting.

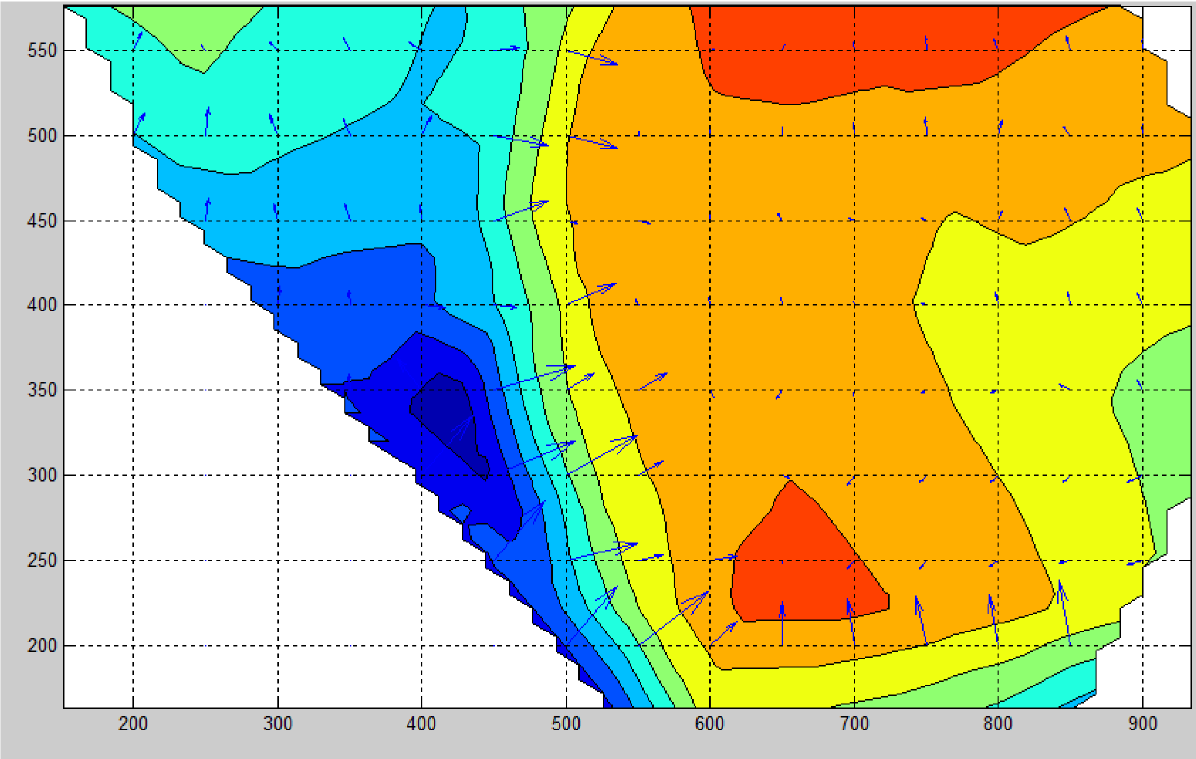


Figure 3: Contour plot with gradient vectors for observer 4

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