Mugla Journal of Science and Technology

SALIENCY BASED ILLUMINATION CONTROL FOR GUIDING USER ATTENTION IN 3D SCENES

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Received: 29.03.2021, Accepted: 14.10.2021 Research Article
*Corresponding author DOI: 10.22531/muglajsci.905213

Abstract

Visual attention has a major impact on how we perceive 3D environments and saliency is a component of visual attention expressing how likely a scene or item is to capture our attention due to its apparent features. Saliency relies upon shape, shading, brightness, and other visual attributes of items. The saliency distribution of a visual field is influenced by the illumination of a scene, which has a significant impact on those visual properties. This work aims to control the saliency by manipulating the illumination parameters in a 3D scene. For this reason, given a sensible 3D scene, the light parameters that provide maximum saliency for the point of interest objects are investigated. In other words, we propose a method for task-aware automatic lighting setup. In this paper, 2D renderings of a 3D scene from various perspectives are considered, and the effects are analyzed in terms of saliency distribution under various lighting conditions. Also, for this process, different saliency estimation methods and calculations are investigated and eye tracker based user experiments are conducted to verify the results.

Keywords: Saliency, illumination, eye tracker, visual attention

3B Sahnelerde Kullanıcı Dikkatine Yönelik Belirginlik Tabanlı Aydınlatma Kontrolü

Özet

Görsel dikkat, 3B ortamları nasıl algıladığımızı önemli ölçüde etkiler ve belirginlik bir sahnenin veya objenin görünür özelliklerinden dolayı ne kadar ilgimizi çektiğini ifade eden görsel dikkatin bir parçasıdır. Belirginlik, objelerin şekil, gölgelendirme ve parlaklık gibi görsel özelliklerine dayanır. Bir sahnenin aydınlatmasının bu görsel özellikler üzerinde önemli bir etkisi vardır. Bu çalışma, 3B bir sahnede aydınlatma parametreleri üzerinde değişiklikler yaparak sahnedeki nesnelerin belirginliklerini kontrol etmeyi amaçlamaktadır. Bu sebeple, gerçekçi bir 3B sahne verildiğinde, dikkat çekmesi istenen hedef nesneler için maksimum belirginlik sağlayan ışık parametreleri araştırılmaktadır. Bir başka deyişle, amaca bağlı otomatik aydınlatma kurulumu için bir yöntem öneriyoruz. Bu çalışmada, 3B sahnenin belirli bakış açılarından 2B ekran görüntüleri ele alınmış ve sonuçlar, farklı ışık pozisyonları altındaki belirginlik dağılımına göre incelenmiştir. Ayrıca bu süreçte farklı belirginlik tahmin yöntemleri ve hesaplamalar kullanılmış ve sonuçlar göz takip testleri ile değerlendirilmiştir.

Anahtar Kelimeler: Belirginlik, aydınlatma, göz takip, görsel dikkat

Cite

Aktay, S., Bülbül, A., (2021). "Saliency Based Illumination Control for Guiding User Attention in 3D Scenes", Mugla Journal of Science and Technology, 7(0), 11-18.

1. Introduction

Our perception of 3D scenes is greatly affected by illumination. Changing how a 3D scene is illuminated by parameters such as light type, and light position makes the details in some areas more perceptible while possibly decreasing the visibility of other details.

Saliency is a measure of visual attractiveness of scenes or objects and it is widely studied in 2D and 3D cases. Saliency depends on geometry, color, size and other attributes of objects [1]. Illumination significantly affects the saliency distribution within an environment.

In this work, the saliency of objects will be identified according to various light locations. The main point of this work is to control saliency by manipulating the illumination parameters in a 3D scene. Rather than simply directing lights to target objects, our aim is investigating the relative saliency of objects with respect to different light setups. For this purpose, a realistic 3D scene is created and the light position maximizing the visual saliency of a target object is investigated. In this process, 2D renderings from a set of viewpoints are considered and output images illuminated with different light positions are compared in terms of their saliency distribution.

To verify the effectiveness of the proposed approach, we conducted user experiments. In the experiments, we used an eye tracker to test if the subject's pay more attention to specific objects within a realistic 3D scene if the illumination parameters lead to higher saliency values for those objects. According to the conducted experiment, the likelihood of user attention towards specific objects can be manipulated with the proposed system. Therefore, perceptually aware light localization is important for the visual attention of users in 3D scenes.

With the proposed approach, the light parameters can be automatically selected to render the important regions more effectively, hence the possibility of the user to look at the relevant places can be increased. In other words, we are trying to determine the optimum illumination parameters to direct the user's attention towards specific regions of interest. The proposed study can be helpful for various applications. One of them is advertisement. For instance, the proposed approach can be used to find out the best light location in a scene, so that users' attention can be optimally directed to an advertised item. Another possible application area is games where illumination can be used to adjust the difficulty of the game; e.g., how the enemies are camouflaged in an adventure game can be controlled.

Also, this project can be helpful for the perceptual guidance of users in virtual reality (VR), for example, it can be helpful in VR museums and thanks to effective use of lighting visitors can pay more attention to important historical objects. Other usage areas may include interior design and education.

2. Related Works

We can group related studies in three categories; saliency measurement, directing user's attention, automatic light setup and eye tracking.

Saliency Measurement. There are many approaches about saliency detection works. An early approach is proposed by Itti et al., [2]. This work considers the center-surround mechanism of the visual attention system and combines multiscale image features into a saliency map. This approach's system breaks down the complex problem of the scene and selects the visual attention objects rapidly. Another saliency detection approach is proposed by Rudinac and Jonker [3] for Indoor Environments. In this method, firstly a saliency map is generated and regions of various sizes are detected using Maximally Stable Extremal Region (MSER) method. Spectral residual approach is used for quickly generating saliency maps. Colour information and computing the log spectrum representation of three channels; intensity, red-green, and yellow-blue are computed. In another study [4], the effect of depth on saliency is explained. This system works with two steps that are the computation of the depth map from the image and using the depth map to compute the 3D saliency map.

In another study [5], authors state that the saliency maps, even from the same input picture, can vary from each other. They also note that the chart of human fixation differs significantly over time. Once people display a picture publicly, they prefer to at first devote focus to large-scale influential regions, and then look for more and more informative regions. In this paper, they argue that visual attention cannot be represented by a single saliency map for one input image and that this function should be modeled as a complex operation. They propose a global inhibition model under the frequency domain paradigm to mimic this process by suppressing the non-saliency in the input image; they also show that the dynamic mechanism is affected by one parameter at the frequency domain. One of the other studies [6], which is proposed by Bruce and Tsotsos, considers the role that attrıbutes of visual stimuli play in example from the stimulus-driven perspective and they present their model for saliency calculation. One of the other approaches [7] is proposed by Krüger et al. and explains their method which develops extension of the theory of visual attention (TVA)'s amplitudes by calculating and modelling salience. A calculation of saliency is taken by linking separate contrasts for a TVA parameter. In the modelling part, the equation related to salience is described mathematically and tested upon to other alternative models using Bayesian model comparison and this comparison shows that power function is suitable model of saliency growth in the dimensions of orientation and luminance contrast.

Directing User's Attention. There are a few studies about directing attention using saliency information. In one of those studies, Kim and Varhsney [8] aim to persuade the viewers to pay attention to specific characters and objects and they argue that luminance, color, lighting, and orientation are important to guide visual attention. Therefore, they use some methods that are region selection, persuasion filters, validation, and stylized rendering for visual attention persuasion.

Another saliency-based study [9] provides an introduction to the retargeting of visual focus, its relation to visual saliency, the issues involved with it, and suggestions about how it can be approached. In addition to the potential negative effect of saliency shifts on picture aesthetics, the challenge of focus retargeting as a saliency inversion issue resides in the absence of one-to-one mapping between the saliency and the picture domain. A few strategies from recent research are examined to address this difficult issue, and a variety of ideas are offered for potential progress. For example, Iterative Black Box approach [10], is proposed for attention retargeting based on saliency calculations.

Automatic Light Setup. To the best of our knowledge, there are no prior approaches in the literature utilizing saliency distribution for 3D illumination setup as proposed in this study. However, there exist several approaches related to automatic light setup. An approach proposed by Zhang and Ma [11] investigates automatic light setup. They propose a method of light design for volume visualization which uses global illumination. To automatically create an optimal three-point lighting environment, their resulting system takes into concern the view and transfer-function based content of the volume data. The backlight that is not used by prior volume visualization systems is completely utilized by their method. Furthermore, they propose an automated operator for tone mapping that restores visual information from over-exposed areas while preserving adequate contrast in the dark areas. Their method is effective for visualizing volume data sets with complex structures. With this approach, structural information is more purely and accurately conferred under the automatically generated light sources. Another study [12] explains a novel strategy in indoor scenes that produces optimum placements and intensities of a series of light. Their method is distinguished by the implementation of objective optimization functions based on the lighting principles which are used in the interior design areas. Their lighting generation system creates a set of lights and decides positions and lighting intensity of the set of lights when a 3D indoor scene is given as an input. For this purpose, firstly they formulate and measure essential elements and add them to the simulated 3D indoor scene concerning guidelines for interior lighting which is used in real-world interior design. After that, they develop a system that facilitates users to create lighting templates. In another approach, proposed by Sunden and Ropinski [13], a method is presented which approves volumetric illumination without requiring precomputation and affecting visual quality. For this purpose, they present selective light updates that reduce the necessary calculations when light settings are altered. This is made possible by utilizing a new propagation method, coherence-based light propagation which incrementally produces and preserves an amount of lighting that is global and selectively modified.

Eye Tracking. There are lots of studies about eye tracking process of environment. One of those studies is proposed by Li and Ohtake [14], a method is demonstrated which show 3D gaze fixation on the same digital object for analyzing gaze choiceness among different subjects. This approach uses the method of image-based 3D reconstruction for determining 3D gaze fixation on 3D environmental model that is reconstructed without using labels. Another study [15] explains multiple methods of eye tracking for packaging. This approach investigates customer's attention to packing images using eye tracker technology and they use different eye tracker technology for determining the customer's attention on the stimuli. In another approach [16], researchers investigate that whether urban environments cause different responses or not according to eye movements and feelings of relaxation. For that approach, the same image set are shown for the 20 subjects randomly and they used eye tracker technology to test.

3. Our Approach

In this paper, we consider the visual attention mechanism for automatic light setup in a 3D environment. According to different light parameters and sources, the saliency of objects alters so they grab a different amount of attention. For instance, when a human enters an environment, she will firstly notice the object that is well illuminated. In our approach, we use a realistic 3D environment (kitchen environment shown in Figures 3 and Figure 5) and placed several objects as the points of interest. The environment is illuminated with various light settings and the camera is placed at the entering location of users. The aim of our method is automatically identifying the optimum light setup to direct the user's attention to any one of those objects. An overview of the applied steps can be seen in Figure 1.

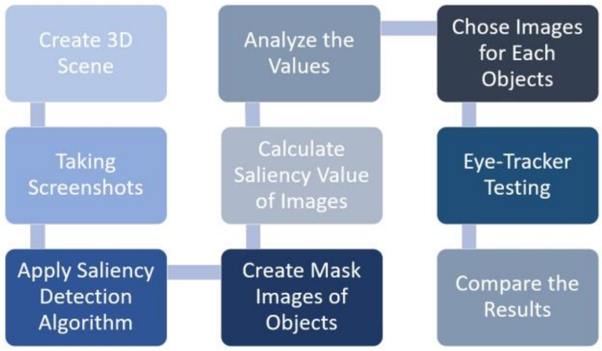

Figure 1. Flowchart of the processes which were applied.

Table 1. Saliency Values of Bowl Object for Two Light Source Case

Image Name	Itti's Approach	Image Name	Fine-Grained
Image 088	5.71	Image 098	4.73
Image 104	5.70	Image 086	4.71
Image 085	5.69	Image 099	4.71
Image 135	4.74	Image 070	3.09
Image 134	4.73	Image 022	3.09
Image 037	4.72	Image 143	3.07
Image 005	4.03	Image 011	1.93
Image 031	3.98	Image 159	1.90
Image 008	3.92	Image 008	1.88

Our approach includes rendering the scene with all candidate illumination settings and determining the best one according to their effect on the relative saliency of the region of interest compared to the whole scene.

Computational saliency estimation aims to determine the degree to which regions or objects stand out to human observers compared to their surroundings. For saliency calculations, we use the two different static saliency algorithms that are Fine-Grained [17] and Itti's approach [2]. Sample saliency measurements' results can be seen in Figures 4 and 6. Static saliency algorithms use different image features that allow detecting the salient object of a non-dynamic image. Firstly, we used the fine-grained algorithm for the saliency calculations. Light angle, light intensity, and light direction make a decisive impact on saliency results. Then, we applied Itti's approach [2] that includes processes which are linear filtering, normalization and linear combinations. After applying two different approach we got saliency results and when the values are compared, we observed that Itti's approach gives better results compared to fine-grained algorithm (See in Table 1) for our purposes. Therefore, we used Itti's approach for the rest of our study.

Given a 3D scene, we have written a script that performs rendering with all lighting conditions. The script changes the light sources' location around the point of interest objects. A 3D kitchen model is used to conduct an experiment with the proposed technique. The reason for utilizing a kitchen environment is its suitability for placing various kinds of objects competing for user attention. In our case, we placed bowl, melon, deep-pan, and glass objects to the 3D environment with one light source case. After these processes, the system automatically took screenshots from the scene that have different light sources' locations for all images and applied the saliency detection steps on these images. In total, the system took 141 images for testing and calculating saliency values and outputs when the environment has one light source. After that, we added different point of interest objects to provide complexity of the environment and we used two light sources. For this case, we placed the light sources to the right and the left around the point of interest objects and a script rendered the scene with all lighting conditions. In total, there are 213 images of the scene to analyze the saliency values for the case that have two light sources on the scene.

To determine the relative saliency of an object compared to the whole scene, we generate masks for the objects (See in Figure 7). For this process, we wrote a script to remove all objects from the scene except the target objects. Then, we created a binary mask that is used to check the saliency values over the region of interest. The average saliency value over the masked region is divided by the mean saliency of the whole image gives the relative saliency of the object of interest. A higher relative saliency value means that the target object stands out more compared to its surroundings. Therefore, we have sorted the images according to their relative saliency values to decide the best light position for each object.

4. Experiment

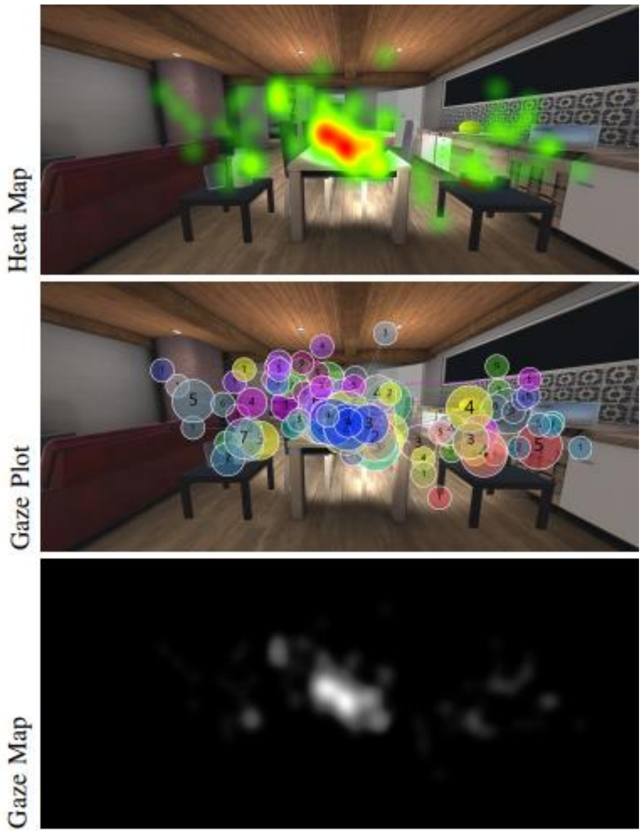

Figure 2. Sample eye-tracker outputs for two light source case including all participants' results

We conducted an eye tracker based experiment for two cases according to number of light sources and we conducted this experiment firstly for four objects under single light source. For the second case, we conducted the experiment with five objects illuminated with two light sources. We used a Tobii 4C Eye Tracker to capture subjects' gazes. In the experiment, the twelve images shown in Figure 3 and fifteen images shown in Figure 5 are used. These images are specifically chosen as they include high, medium, and low saliency values for each target object. Fourteen subjects with an average age of 33.07 voluntarily participated for the first case of the experiment. There were 7 female and 7 male subjects. For the second case of the experiment, there were 21 (7 female and 14 male) subjects with an average age of 31.76 who participated voluntarily. All subjects had normal or corrected to normal visions.

We used a 15.6-inch laptop display to present the stimuli to the participants. For each subject, firstly we calibrated the eye tracker device using Tobii Eye Tracker Manager Software. The subjects are told to look at the presented images freely without a specific task. To avoid the inhibition of return effect [2] from continuously looking at the same scene, the actual stimuli is mixed with irrelevant images. At the beginning of the experiment, the subjects are shown four irrelevant images before presenting the actual stimuli.

After that, we presented three irrelevant images between each pair of the actual stimuli. Each of the actual and irrelevant images was shown to subjects for two seconds and we did not extend the time for each image to avoid their inspection of the scene.

After the experiment, we have investigated whether the users are focusing on the intended objects or not by creating a heat map from the user gazes. Also, we could observe the results by gaze duration of users to the points (Figure 2-Gaze Plot). After obtaining the results, we generated user gaze maps where brighter regions indicate the regions that are looked at by the users to a higher degree. Then, similar to the calculation of relative saliency values explained in Section 3, we used object masks over the gaze maps and calculated the user saliency values over the objects of interest. Dividing the mean saliency (gaze) value over the masked region to the mean gaze value over the entire image provides the relative user saliency of the objects. Following this process, we obtained relative user saliency values for each user and each object.

Using Tobii Pro Lab platform, we could see the results with different forms as shown in Figure 2. This Figure shows the heat map, gaze plot, and gaze map outputs of second case of experiment for melon object with high saliency value which have the most successful light position for the melon object, in addition these results include all participants' results. According to output images, we can say that participants firstly focused on the melon object, then they investigated the environment. According to the light position, focused objects seem to be correctly estimated and they are compatible with the highly salient melon object. We analyzed all cases according to user attention as demonstrated in Result and Discussion Section.

5. Results and Discussion

For this project, we firstly analyzed 141 images that were from the scene with different light conditions using one light source and later, we took 213 images that are from the scene with two light sources. Table 1 shows, relative saliency values for the bowl object over 9 different lighting calculations with both one light source environment and two light source environment. In Table 1, the first three values are the three highest values, and the following three values are the middle values of them and the last three values are the smallest values from saliency results of bowl object with two different approaches' results. According to the results of Table 1, we obtained that Image 088, Image 104, and Image 085 have a successful light position for users to attract the attention of bowl objects with Itti's approach' results and Image 098, Image 086 and Image 099 have a successful light position according to our algorithm. The saliency values change according to light condition and the target object. If the saliency value of an object is higher than others that indicates the scene has a successful light condition for the specified target object.

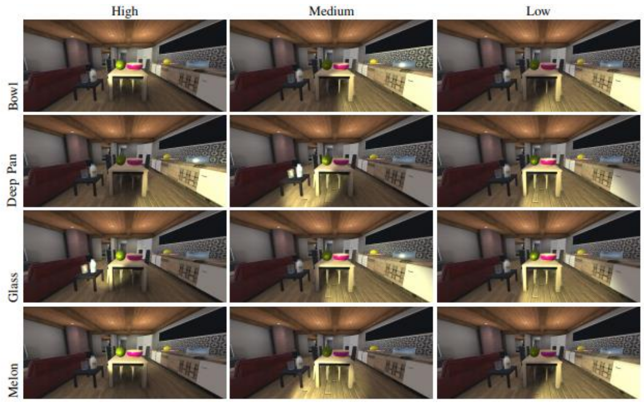

Figure 3. Screenshots from the scene which has one light source according to light location

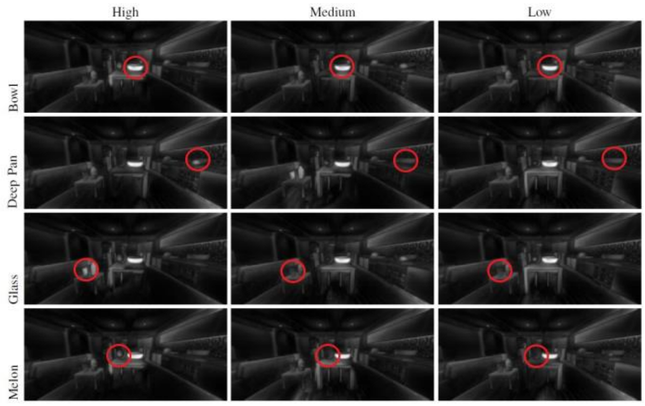

Figure 4. Saliency map results from the screenshots

In Figure 3 images were grouped according to values that are calculated using Itti's approach calculation. For Figure 3 grouped table, we selected twelve images from 141 images, three for each target object, with the highest, middle, and low prominence values of each object. The saliency value change according to light condition and the target object. Therefore, the highest value's image has the successful position of the light according to the interest object. For instance, in the image showing the highest value of the bowl object in Figure 3, the light is coming directly to the target object, hence the bowl object draws attention due to the light conditions it has when people enter the scene. The image which has medium saliency value of the bowl's light condition is not directly to the target object, thus the result is an average value. Finally, the image which has a low value has a light condition that is not directing attention to the target object. Also, output images can have successful light conditions according to other target objects which are deep-pan, glass, and melon. For instance, the medium value of deep-pan image light condition is successful for glass object to be interested in by people. Consequently, lighting conditions are significant for people to attract the attention of objects, and light conditions can affect target objects' attention. Also, Figure 4 has the saliency map results of each image that are in Figure 3.

In Figure 5, images were grouped as t to values in the tables of objects. For Figure 5, we selected fifteen images from 213 images that are screenshot from the environment which has two light sources, three of each point of interest objects, with the highest, middle and low saliency values. For instance, in Figure 5, for the melon object, the image which has highest saliency value has the successful light condition according to other objects, for this case two light sources are intersected on the melon object region so this image has the highest saliency value. For the middle value of the melon object, light sources are intersected but not interlaced, so this value is the middle value of the melon object. Finally, for the low value of the melon object, light sources are apart from each other, one on the right and one on the left, hence the saliency value is the lowest.

According to tables that are for all objects with one light source or two light sources environment. Objects which have highest saliency value in environment that has one light source increase since there are two light sources and so when the light sources are intersected the saliency value is higher than the before values. For instance, for bowl object the highest saliency value is 5.2 when the environment has one light source. When the environment has two light sources, the highest saliency value of the bowl object is 5.7. In addition, we added other objects on the environment and we investigated the only small bowl. For some case, post-added objects may be distracted for user's attention, therefore some values are not better than the previous results.

After the eye-tracking based user study, we checked our results to see if we can direct the user's attention to the intended object. For the first case of experiment, we used the 12 selected images having high, medium, and low saliency values for each target object. The user gazes were collected for each of the 12 images and we analyzed if the users are paying more attention to the objects when the illumination conditions are providing more saliency values for them. Similarly, for the second case of experiment, we used the 15-chose images having high, medium and low saliency values for each target object and we investigated users' attention using same process with first case of experiment.

The user-based relative saliency values were calculated by dividing the mean brightness value of the heat map over the masked region by that of the entire image for two cases of experiment. Such an approach provides how much attention is paid to a specific region compared to the entire scene; thus, a value of one means that the region receives the average amount of user attention. Although, for each user, relative saliency values vary; in general, the relative user saliency values change as expected. After calculating the saliency values of eye tracker outputs, we created a plot for the first case of experiment (See in Figure 8) which shows the results of the user study and we created a plot for the second case of experiment Figure 9.

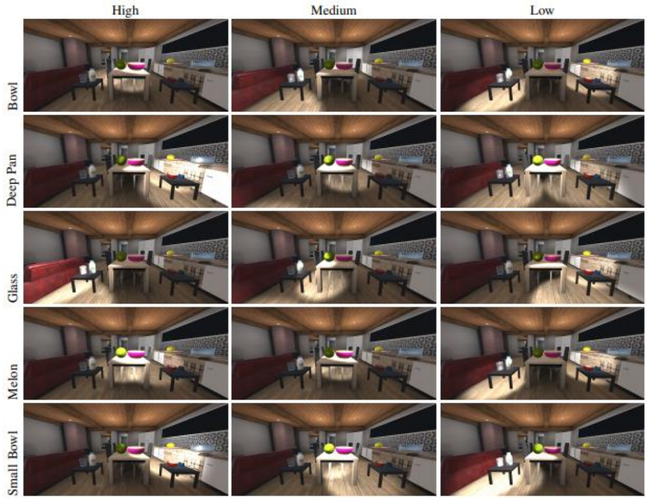

Figure 5. Screenshots from the scene according to light location which has two light location

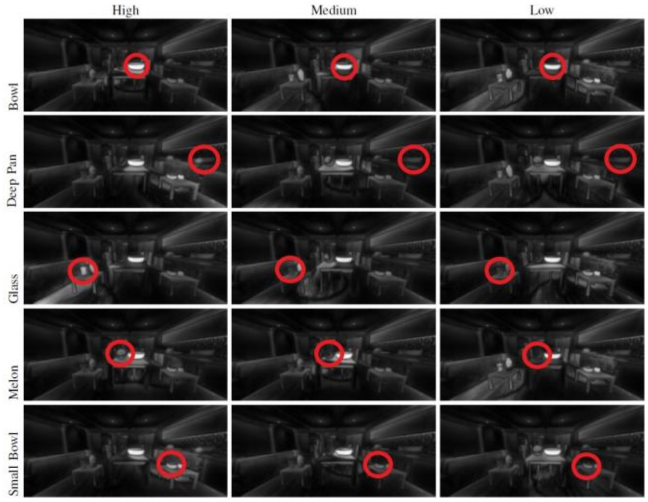

Figure 6. Saliency map results from the screenshots

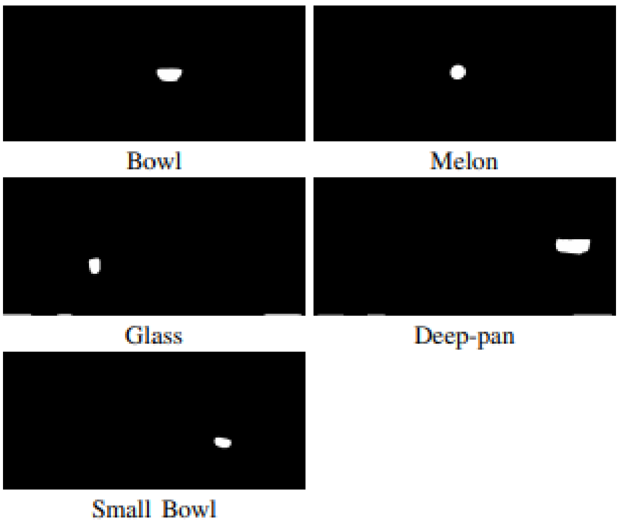

Figure 7. Masks of the target objects

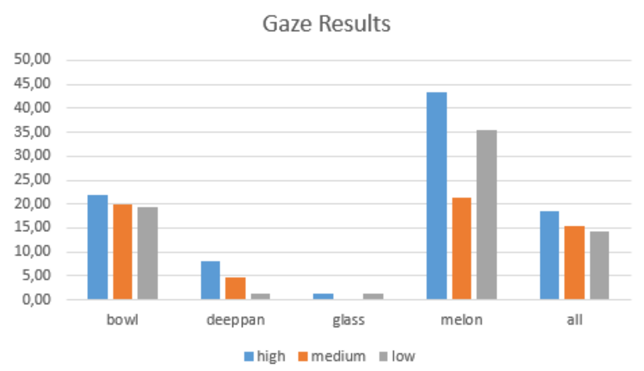

Figure 8. Results of the user study for first case of experiment.

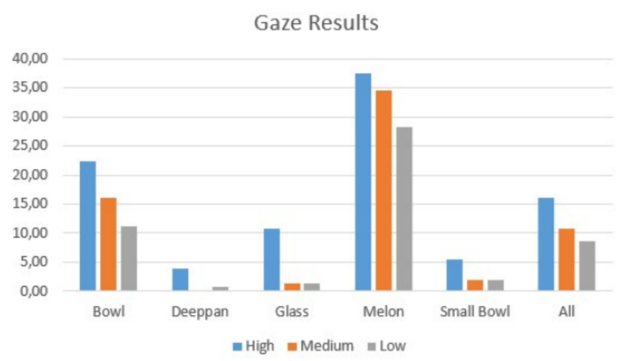

Figure 9. Results of the user study for second case of experiment.

These plots include the average of each objects' saliency values according to the user study. Moreover, the high saliency values mean that images that have a successful light position and draw more attention from people according to lower saliency values of the images. Although eye-tracking test results continue by decreasing from high saliency image to low saliency image as in our results in Section 3, there may be problems during the testing process. Therefore, there is a margin of error in the values because of users sitting position, attention concentration, etc.

For the scene that has one light source, we calculate the average saliency using eye-tracking user study. For bowl object, results are expected in decreasing from high to low, also for deep pan and average of all objects values are expected according to our calculations. To the scene which has two light source, our user study investigation is expected to our calculations. Except deep pan object, other four objects' saliency results are expected to our relative saliency calculations. Because of two light sources, our results are more obvious than the one light source results.

To check statistical significance of the results for second case of experiment results, we applied a paired t-test for the values of all objects' gaze values and the whole objects' saliency measurement values using Itti's approach and we found statistically significant correlation between user gazes and relative saliency values ($p < 0.001$). Considering all objects t-test results, we have obtained significantly different user attention according to the applied t-test results ($p < 0.05$). Moreover, we found significant effect of illumination and high, medium and low values of are parallel between the experiment results and the saliency measurement values of all objects.

6. Conclusion

To conclude, in this study, we have investigated the use of the human visual attention mechanism for automatic light setup. The main purpose of this work is examining the light directions to get better relative saliency values of objects. To do that, a realistic 3D scene is used and the light position maximizing the visual saliency of point of interest objects according to a given viewpoint is searched for. In this process, 2D renderings are rendered from a range of perspectives, and resulting images illuminated with various light positions and different number of light sources are measured in terms of their effect over the distribution of salience. Eventually, we checked whether the results reflect the reality by using an eye tracker based user experiment and achieved promising results. Visual attention is significant for advertisements, game scenes or VR applications such as virtual museums that have objects of special importance and our approach can be used to make them more noticeable to the user by positioning the lights to direct user attention to specific regions.

In the current form of the study, we have only investigated light directions, which is a part of the whole illumination setup. In future studies, we are planning to consider more exhaustive lighting parameters and various viewpoints. Another point of concern is delivering a visually plausible rendering for the whole scene while still trying to direct user attention to specific objects or regions, e.g., a rendering where only the object of interest is illuminated is not the desired one as we will lose the context. Thus, in the future study, we will have more concerns to consider while selecting lighting parameters and it will form a larger optimization problem.

Acknowledgement

We would like to thank all participants of the conducted experiments.

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