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Computer Graphics I

Literature Review I: The Inverse Rendering Problem

For this literature review, I chose to review two papers that each propose different solutions to the Inverse Rendering problem, the goal of which is to accurately find the surface reflection properties of objects in a real image so that a synthetic image of the same objects can be created with varied lighting conditions. My primary paper is "Interactive Relighting in Single Low-Dynamic Range Images", which was written by Jung-Hsuan Wu and Suguru Saito for the April 2017 edition of the "ACM Transactions on Graphics" journal. Meanwhile, my secondary paper is "Light Source Position and Reflectance Estimation from a Single View without the Distant Illumination Assumption", which was written by Kenji Hara, Ko Nishino and Katsushi Ikeuchi for the April 2005 edition of IEEE's "Transactions on Pattern Analysis and Machine Intelligence" journal.

For the sake of clarity, the Inverse Rendering problem refers to the difficulty in realistically re-lighting an image whose existing light sources are not all distant. When lighting a scene lit by a distant illumination source, like the Sun, the light produced can be assumed to follow orthogonal projection (i.e. that all light rays transmitted are traveling in the same direction) and parallel illumination (i.e. light rays are spread out with equal intensity when reflecting off a surface), which makes calculating what direction light will be traveling in and how intense said light is easier to calculate. However, these assumptions cannot be made for images that are lit by a non-distant light source, such as a city street at night or a fully indoor environment, since the direction and intensity of the light rays produced would not be as uniform. In response, both of the papers I've selected propose their own solutions to this issue, each with varying degrees of success.

Starting with my secondary paper, "Light Source Position and Reflectance Estimation from a Single View without the Distant Illumination Assumption" proposes two different methods for solving the problem. Both solutions are constructed with the Torrance-Sparrow reflection model in mind, which rationalizes how light reflects off a surface as a combination of two different areas where light behaves differently: a specular reflection area where the light impacting the object is reflected all in one direction, and a diffuse reflection area where light impacting the object disperses equally in all directions, following Lambert's cosine law. While both reflection types are important, this paper puts special emphasis on finding the specular reflection parameters.

In the first method, the user gives the program the real image meant to be modified and a 3D model of the area in the picture, with the model containing pre-entered values for each object noting that object's rate of specular reflection. The program then estimates for each object the dimensions of the diffuse reflection area, then uses the result to calculate the distance between the object and its original source. Next, the program finds the position of the light source relative to each object in the room using the parameters found previously, which then allows it to estimate the rate of diffuse reflection. The parameters for specular reflection can then be trivially found by factoring diffuse reflection out of the original image.

The second method proposed is similar to the first except that instead of the user inputting a normal image, the user inputs a specular component image, an image obtained via the combination of multiple polarized images taken of the same object from the same view. Under this method, the position of the light source and the specular reflectance properties of each object are estimated by assuming that these properties can be modeled uniformly using the Torrance-Sparrow model. Once these values are calculated from the model, the method optimizes the light source's calculated position by adjusting the calculated distance between the light source and the object based on a degree of error that results from the presence of other light sources. Finally, based on the texture of the surface that light is reflecting off of, the method proceeds to estimate the diffuse reflection parameters for each pixel lit. This estimation will not be as accurate as the previous method since this parameter is being estimated based on leftover parameters from specular calculations rather than being calculated separately. However, this inaccuracy is considered negligible in the long run.

In conclusion, this journal entry found that their two methods were able to alter the lighting in a virtual scene to at least a minimum level of plausibility. The methods displayed are certainly advanced for the time it was published and they are adequate for accomplishing the paper's ultimate goal: to create realistic light for simple virtual environments. However, the model they devised is limited in application because, since it puts most of its emphasis on specular reflection, it assumes that the surface of each object that light is reflecting off is generally flat and consistent so that the reflection calculated appears plausible. While this limitation is fine in simpler indoor environments where light must only reflect off walls, the floor, or other similar flat surfaces, this method becomes less effective when applied to objects that have more complex surface areas, such as grass.

In response, the primary paper I chose, "Interactive Relighting in Single Low-Dynamic Range Images", attempts to solve this issue by proposing a method that puts a greater emphasis on diffuse reflection calculation. This direction was chosen because calculating diffuse reflections as the focus still allows for the estimation of a light source's position whilst providing lighting modifications that appear much more plausible on complex geometries than specular reflection methods do. This method also improves on the ones given previously by only requiring a single low-dynamic range image and a few user annotations in order to function properly and providing the user an interface that allows them to precisely alter the lighting of the image.

To summarize, this method attempts to estimate the distribution of light in a scene by taking into account the position of the camera, the percentage of light reflecting off the objects' affected, and the positions of light sources in the scene. To begin, the user is asked to input the image to be edited and, using the program's interface, indicate the location of the brightly-lit portion of the image to be modified as well as the location of the boundary between the walls of the scene and the ground. The program then reconstructs the scene in the image as a 3D environment and attempts to re-create the lighting conditions in the marked area by calculating the bright spot's average distribution of light intensity. The calculated distribution is then applied as a gradient in the area where the light was positioned in the original image.

However, to avoid the resulting light from appearing artificial, a pixel-wise confidence map is made from the original image. This map assigns every pixel in the indicated area with a weight based on how closely the light in each pixel matches the calculated luminance distribution. If a pixel matches closely enough, its given a high weight and its pixel's color is given the value calculated by the distribution. If a pixel doesn't match the distribution closely enough, either because of shadows, overlapping light sources or imperfections in the image, then it is given a low weight and is only partially colored according to the distribution, with the remainder of the detail being the color of the ground assuming no light was on it. This addition lends the final, synthetic image a greater sense of realism by preserving the irregularities in the original light source.

In conclusion, this method appears to be significantly more effective than those given by its predecessor. While the results of testing with their algorithm found that the synthetic images produced were still far from realistic, they were within a tolerable enough range that they appear plausibly real to the untrained eye. There are scenarios that the paper's solution doesn't account for, namely that the algorithm can't handle black-lighting, exceedingly intricate light patterns (such as lights shining on a carved statue), and images that have had their tone altered through other programs. Nevertheless, the robustness of the simulated lighting produced and the minimal amount of materials to function properly are worthy of praise.

Bibliography:

1) Interactive Relighting in Single Low-Dynamic Range Images

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@article{Wu:2017:IRS:3068851.3034185,
 author = {Wu, Jung-Hsuan and Saito, Suguru},
 title = {Interactive Relighting in Single Low-Dynamic Range Images},
 journal = {ACM Trans. Graph.},
 issue_date = {April 2017},
 volume = {36},
 number = {2},
 month = apr,
 year = {2017},
 issn = {0730-0301},
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 url = {http://doi.acm.org/10.1145/3034185},
 doi = {10.1145/3034185},
 acmid = {3034185},
 publisher = {ACM},
 address = {New York, NY, USA},
 keywords = {Image-based relighting, image-based modeling},
}
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2) Light source position and reflectance estimation from a single view without the distant illumination assumption

@ARTICLE{1401904,
author={K. Hara and K. Nishino and K. lkeuchi},
journal={IEEE Transactions on Pattern Analysis and Machine Intelligence},
title={Light source position and reflectance estimation from a single view without the distant illumination assumption},
year={2005},
volume={27},
number={4},
pages={493-505},
keywords={computer vision;light sources;parameter estimation;reflectivity;relaxation theory;Lambertian diffuse component;finite distance illumination;iterative relaxation scheme;light source position;multiple polarization images;reflectance estimation;reflectance parameter estimation;source-surface distance modification;specular component image;H infinity control;Image analysis;Indoor environments;Iterative methods;Light sources;Lighting;Optical polarization;Optical reflection;Reflectivity;Solid modeling;Index Terms- Finite distance illumination;light source position estimation;reflectance parameter estimation;specular reflectance.;Algorithms;Image Enhancement;Image Interpretation, Computer-Assisted;Information Storage and Retrieval;Light;Photometry;Radiation Dosage;Radiometry},
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