3D Simulation of Prints for Improved Soft Proofing

Rohit A. Patil, Mark D. Fairchild and Garrett M. Johnson
Munsell Color Science Laboratory, Rochester Institute of Technology
Rochester, New York, USA

Abstract

A display tool has been developed to perform simulation and three-dimensional rendering of prints in the quest towards achieving improved soft proofing capabilities. It was desired through this 3D simulation that the gloss and surface properties of hard-copy prints be represented on a display, which are absent in current 2D soft proofing workflows. The procedure is described along with the relevant historical work. The major components of the workflow are identified as: the gloss prediction model, and the representation of this gloss on a display using computer graphics rendering techniques. Psychophysical experiments were carried out to evaluate the usefulness of this 3D simulation over current 2D soft proofing technique.

1. Introduction

Proofing is an important step in the printing workflow, whereby it is desired that it provide an accurate estimation of what a final print will look like. Proofing can be broadly classified as pure hard-copy proofing, digital hard-copy proofing (also known as computer-to-plate) and soft proofing.[1,2] While, pure hard-copy proofing has lost its edge over the other methods; digital hard-copy proofing is still the preferred choice as final proof over soft proofing.[3] Soft proofing is representation of the final print on a display device and is of value only if the representation is accurate for the required purpose.[4] Soft proofing is a cost efficient and a speedy alternative to hard-copy proofs. It is also of prime importance for remote proofing. Unfortunately, soft proofing has not yet reached its full potential and is merely serving as a step before producing final hard-copy proofs.[3,4] The roadblocks for soft proofing could be attributed to the fact that the two media, soft-copy and hard-copy, are inherently different. This difference in media presents challenges in terms of appearance matching as well as potential differences in device gamuts. A soft proof also lacks the feel and substance of a hard-copy.

A color match in terms of CIE colorimetry can be achieved between images on the two media if the same chromaticities and luminance are produced. An appearance match is possible only if the viewing conditions in which the two media are being compared are the same, and are tightly controlled. Standards in the form of ISO 3664 and ISO 12646 (in draft stage) exist, which make recommendations in terms of viewing conditions to be followed. But, even in such situations complications arise in terms of chromatic adaptation and color appearance differences, since soft copies are self-luminous while hard copies are reflection images.[5,6]

It is not always possible, though highly desirable, that the two media have the same color gamut. So, if all the possible colors reproducible by the printer are not displayable, even an exact colorimetric match is out of the question. Hence, certain colors cannot be displayed and this will remain a drawback. This drawback could be largely negated by clever selection of a gamut mapping algorithm. An in depth review of the topic can be found in Braun[7].

Given these conditions, the quest for better print simulation (soft proofing) strategy continues. Laihanen[8] has underlined the importance of spatial variations in contributing towards the color differences between hard-copy and soft-copy images. To account for these spatial factors, Laihanen proposed an algorithm claiming a significant improvement in color prediction on displays. In another study, Usui[9] has developed a print simulator for displays based on spectral data. The simulator uses various coefficients representing printer characteristics which make it possible to accurately display the colors that would be printed by the printer. In a more recent study, Heikkila[10] has proposed a “device resolution profile” which can be used to simulate the resolution effects of a reproduction device. Its use for the purpose of soft proofing is emphasized.

It should be noted that all of the strategies discussed above try to simulate the hard-copy and display the soft-copy in two dimensions. While the authors feel that this is important, it is evident that 2D soft-copy images do not represent a lot of important attributes of hard copies, like gloss and texture. Hard copies, viewed in everyday environments, are inherently 3D and these attributes play an important role in observer evaluation of the hard-copy. It is hypothesized that simulating the hard-copy in three dimensions will be an important step towards achieving the goal of improved soft proofing (and perhaps generating more rewarding electronic books). The purpose of this study is to develop a 3D soft proofing tool that would empower users with a better way of evaluating the simulation. It is desired through this simulation, that the gloss and surface properties of hard copies be represented accurately and these should be able to be tracked with changes in viewing conditions, like geometry or lighting. The 3D simulation tool developed is evaluated psychophysically in the quest for answers to these questions. Are such images considered significantly closer in appearance to the final print over 2D images? Are users more forgiving of color inaccuracies in the print simulation if other aspects of the simulation, like gloss, are better?

2. Gloss as Appearance Attribute and its Measurement

Gloss forms an important geometric attribute that affects appearance of a hard-copy after 'color'.[11] Gloss gives a shiny appearance to a surface and is generally considered as a factor of specular reflection. Hunter[12] has described six different types of gloss that could be distinctly identified by human observers. Most of these distinct glosses are rarely observed on prints and are discarded for the purpose of the study of print gloss.[13] Specular gloss or shininess is considered as the important gloss type for this study and will be referred to as 'gloss' henceforth.

Many studies are being performed on evaluating the effect of gloss on perception of color and image quality of printing systems. Recently, an ad-hoc team called International Committee for Information Technology Standards (INCITS) started working on W1.1 project involving standardization issues of perceptual based gloss and gloss uniformity for printing systems.[14] It has been emphasized that the perceived color of a print is significantly affected by its gloss. The gloss of a print in turn is determined by the printing technology employed and the substrate used. For example, the toner properties, fusing temperature, speed and substrate used in xerographic method will significantly influence the gloss and hence the color.[15]

Measurement techniques for specular gloss are well established in the form of ASTM D523 and TAPPI T480 standards. It should be noted that the relationship between these instrumental based gloss values and visual perception of gloss is not very well understood, and these instrumental values just place the measured stimuli in the correct rank order as perceived visually.[11] ASTM method D523 specifies three different geometries to measure specular gloss.[19] G60 gloss, wherein the source and receptor apertures are at 60^0 with the normal to the paper surface, is recommended within the 10 – 70 gloss units. Since several substrates were used for this study that had gloss values less than 10, much lower for matte substrates, it was decided that the 85^0 measurement geometry will be used to provide enough sensitivity.

3. 3D Rendering of Prints

3.1 Workflow

This section gives an overview of the workflow adopted in developing the 3D simulation tool. The tool was developed keeping in mind the aim, that it should display a 3D image of print on a monitor and allow users to move this image so that the change in gloss could be tracked along with giving the feel and substance of hard-copy. Current advancements in the field of computer graphics make it largely possible to achieve this aim. The general requirements for computer graphic rendering are very well described by Hunt *et al.*[17] Rendering of a scene requires the knowledge of the light reflection properties of objects in the scene. This can be obtained in different ways. Several devices have been developed, see Gardner *et al*[24] for example, that capture the sample's Bidirectional Reflection Distribution Function (BRDF), which contains all the required gloss information. But measuring BRDF is a difficult and expensive procedure. As an alternative, numerous parameterized light reflection models have been proposed in the field of computer graphics that try to describe these light reflection properties and hence determine its appearance. This reflection can be usually separated into diffuse and specular components. The diffuse component is independent of the viewing direction, hence always present, providing color information, while the specular component is largely dependent on the viewing direction and is added accordingly, providing gloss information.

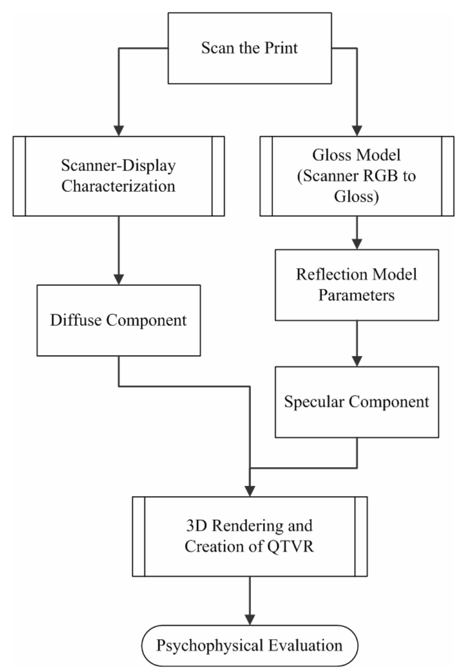

Figure 1. Flowchart showing the steps followed in creating and testing the 3D print simulation tool

Figure 1 shows the workflow adopted for developing and testing the 3D simulation tool. The image is printed using an RGB image. This print is then scanned at a high enough resolution (e.g. 2400 dpi) to capture individual dots, which serves two purposes. These scanner digital counts are converted to tristimulus (XYZ) values, using scanner characterization, which in turn are converted to final display

RGB scalars, using display characterization, to be used as the diffuse component in the reflection model. These scanner digital counts are also used to predict the inks present on the print which are fed into the simple gloss prediction model, described later, to determine the gloss for each pixel. The parameters of the light reflection model are then calculated using this predicted gloss, which defines reflection properties of the print. Using this reflection model and a customized shading algorithm, 3D images of the print are rendered at different view angles. These images are then assembled together using image based rendering software QuickTime® VR[18] to create an interactive tool that observers can use to change the viewing angle of the print and also zoom in, giving real time impression.

3.2 Scanning and Gloss Prediction

To represent the gloss information of the print, a simple print gloss prediction model was built. Previous research has shown that the measured gloss changes with the toner density and also depends on the actual toner color (C, M, Y, K or their overprint).[13] Initial investigation showed that the entire gloss range of the printer-paper combination can be well captured by gloss measurements of paper, pure Cyan, Magenta, Yellow and Black inks, their two color overprints Red, Green and Blue and four color (CMYK) black. These nine entities form the primaries of the gloss prediction model. These nine primaries were printed and their gloss was measured using BYK-Gardner micro-Tri-gloss meter and geometry mentioned earlier. This target was also scanned to get the scanner digital counts. Thus, the measured gloss and the scanner digital counts of these primaries are the requirements of the gloss prediction model.

Once these data are available, the print to be simulated is printed and scanned at high resolution so that each scanned pixel is either paper, pure ink color, their overprint or some combination of these caused by scanner optical blurring. Using the scanner digital counts of each pixel and the digital counts of the primaries of the gloss prediction model, the three closest primaries (inks) to the scanned pixel are determined. This is based on the assumption that the scanned pixel is one of the nine primaries or combination of three of the nine primaries. Once these three primaries are identified, simple bilinear interpolation on their measured gloss is performed to predict the gloss of the scanned pixel. The model gives zero error when the scanned pixel is exactly one of the nine primaries while small errors in gloss estimation are obtained for pixels that are some combination of these. The average percent gloss estimation error for six different printers was 9.66. These errors are found to be acceptable for this application.

3.3 Shading Algorithm and Rendering

The final aim is to accurately represent this predicted gloss of each pixel on a display device. For this, a customized per pixel shading and rendering algorithm was developed which consists of two important parts:

1. Determining reflection model parameters from predicted gloss
2. Rendering of the print

As mentioned earlier, reflection models are required in 3D computer graphics to represent the light reflection properties of an object. These models use certain parameters which should be determined. For this study it is required that this parameter should accurately represent the predicted gloss of the print. Important work has been done in this regard by Westlund and Meyer.[20] They have developed an application called “virtual light meter”. This virtual light meter is based on the correspondence between the reflection model parameters and appearance measurements like gloss and haze. Many different reflection models are available in the implementation, whose parameters could be estimated from the measured gloss. It allows inputting gloss values measured using any of the ASTM geometries given in the specification[19] and the parameter for the corresponding reflection model could be estimated. The virtual light meter was obtained from its authors.[20]

The Phong Reflection model was originally proposed by Phong in 1975.[21] Subsequently Blinn[22] modified the model and Lewis[23] modified it to make it physically plausible. The Phong model modified by Blinn is used for this study. This model was chosen for its simplicity and its popularity in the computer graphics world. This model has a parameter ‘n’ called the Phong exponent that simulates the material’s shininess, which is useful for the tool being developed. The virtual light meter described earlier was used to construct a 1D look-up table of Phong exponent versus measured 85^0 gloss.

This Phong reflection model could be divided into diffuse and specular components. The diffuse component is obtained from the scanner characterization and display characterization as described earlier. This ensures the displayed colors are colorimetrically accurate representation of the hard-copy. The specular component is obtained from the Phong exponent determined from the predicted gloss of each pixel and 1D look-up table constructed earlier. The final rendering was done using OpenGL and consists of following steps.

1. Each scanned pixel is represented as a rectangle in 3D using OpenGL.
2. The color of this rectangle is set using the reflection model, whose parameters are determined using the procedure described earlier and selecting proper lighting and perspective viewing.
3. A high resolution image (same as the scanned image) is rendered to an off-screen buffer using OpenGL, which is stored in TIFF format.
4. Large number of images from different view angles, spanning the hemisphere above the paper surface, are rendered and stored.
5. These images are then assembled together in QuickTime® VR to create the final tool which empowers users with interactive features giving the

impression of real time. Users can move the soft-copy, simulating tilting of an actual hard-copy, and also zoom in.

4. Example Renderings

To get a preliminary look at how well the 3D simulation tracked the desired changes in gloss and color, simulations were done for two different printers and three different substrates. The renderings are that of the NCITS W1.1 Differential gloss test chart.[14] The total number of simulations was four. The first simulation consisted of a print, from a laser printer on plain 20LB paper. The other three were prints made using an inkjet printer on three different substrates: glossy, semi-glossy and matte, varying in their gloss property. Some of the example renderings are shown in *Figure 2* and *Figure 3*.

The first row in *Figure 2* shows three different view angles of the simulation of laser printer printed hard copy. Second row is that of inkjet print on a glossy substrate, while the third and fourth rows are that of same inkjet prints but on semi-glossy and matte substrates, respectively. A fixed point light source was used to do these renderings. The first column is a grazing angle view of the print. The first and second columns clearly show the gloss differences on different substrates. A sharp reflection of the light source is observed on the glossy print, which spreads for the semi-glossy one while it totally disappears for the matte substrate. The third column shows a view of the simulation where no specular component is present for any of the prints. This gives an insight on the change in colorimetric attributes with the change in substrate. The matte print looks lighter with lower chroma than the corresponding glossy print, in the simulation, correlating with the appearance of the prints. Thus, *Figure 2* clearly elucidates the potential usefulness of the simulation whereby the gloss and color changes are tracked accurately.

The scanning of the print in the workflow also allows capturing various surface properties and print defects. This is seen in *Figure 3*. The first row shows the zoomed in portion of the simulation of laser printed hard-copy, while the second and third are that of inkjet printed prints on semi-glossy and matte substrates. The superior texture quality of the inkjet printer is clearly seen by the smoothness of the print depicted by the simulation. These renderings shown in *Figure 2* and *Figure 3* have definitely underlined the usefulness of the tool towards reaching our aim of improved soft proofing.

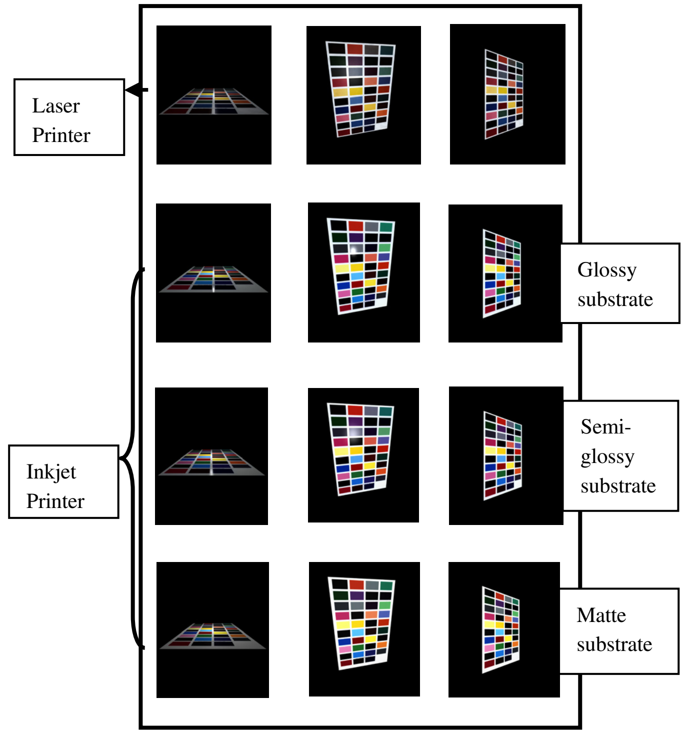

Figure 2. Example renderings for two different printers on different substrates showing gloss and color changes tracked by the simulation

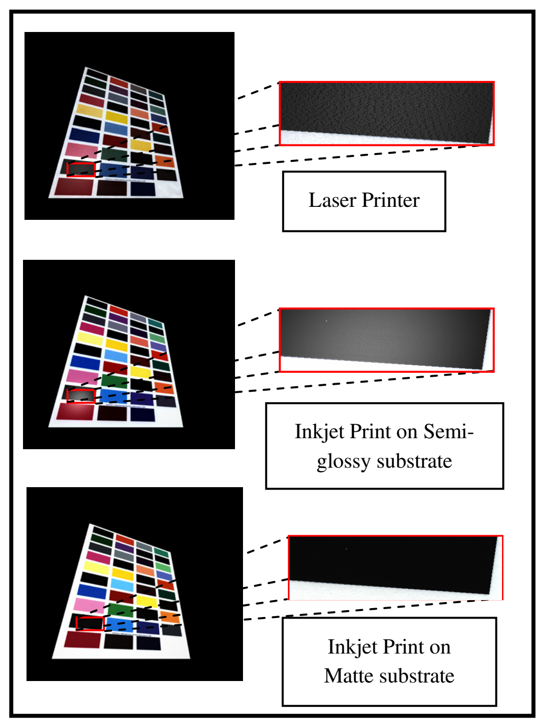

Figure 3. Example renderings showing zoomed in portion of the simulation to elucidate texture differences.

5. Psychophysical Evaluation

5.1 Experimental Design

The usefulness of the tool is seen from the example renderings and initial observations. Two psychophysical experiments were carried out to evaluate the extent of usefulness of the 3D simulation. It was desired that different printing technologies along with different substrates be simulated and then the 3D simulation tool be evaluated. Hence, four different printers were used. Also, five different images/scenes were used to account for any image content dependency. Three of these printers used the same media to print the images while the forth printer used three different media types, namely, glossy, semi-glossy and matte. Thus, each image had six variations (A-F).

Three sample sets were available for each experiment. The first was the print hard copies, second was the 2D colorimetrically corrected images and the third being the 3D simulation set. The 2D images were obtained by scanning the prints and color correcting them through the scanner-display characterization. The 3D simulation set was obtained as described earlier. The experiments were performed in a print viewing room configured with fluorescent illuminators approximating D50 at 2000 lux. The prints were viewed on a viewing table under these lights while the 2D and 3D simulations were viewed on a high resolution IBM display kept in the same room. The display was separated from the viewing table by a black curtain and it was also surrounded by black cloth to minimize flare from the lights above the viewing table.

5.1.1 Print Identification

The first experiment was designed to evaluate the increase in accuracy, and confidence, of the observers, achieved by the 3D simulation over the 2D images, if any. The original hard copies of each image were laid on the viewing table, while the 2D colorimetric simulations of each of these prints were presented on the display one by one in random order. Observer's task was to identify which of the prints on the viewing table labeled A-F was displayed, along with indicating the level of confidence, from 1-9, with which they made their decision; 1 being the least confident and 9 being most confident. Similarly, the 3D simulations were presented on the display after the 2D part was done, observer's task being the same. Observers were allowed to handle the prints, which were mounted on protective frames, and also used the interactive features of the 3D simulation. A total of 23 color normal observers did the experiment.

5.1.2 Paired Comparison

The second experiment was a paired comparison experiment which had three parts. In the first part, observers were shown two prints and asked to choose the print they preferred. The prints were placed on the viewing table by the experimenter in random order. In the second part, two 2D images were shown on the display and observers had the similar task as the first part, in which they had to choose the image they preferred. In the third part, two 3D simulations were shown and the observers had the same task as in the first two parts. In all the three parts, the order of presentation was randomized for each observer. The five images and six variations of each image gave a total of 75 observations for each observer. A total of 22 observers did this second experiment.

5.2 Results and Discussion

The data obtained from the print identification experiment were analyzed first. When the simulation shown on the display was correctly identified from the prints shown on the viewing table, it was counted as a correct answer. *Figure 4* shows the % correct answers across all the observers for each printer, with the error bars representing the 95% confidence interval.

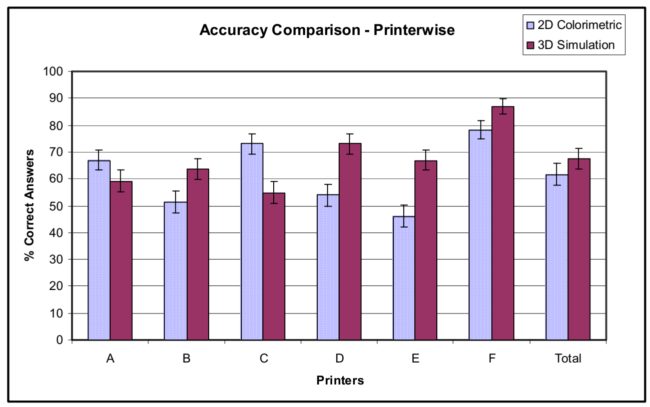

Figure 4. % Correct answers across all observers for each printer.

Figure 4 shows approximately 6% increase in correct answers when the 3D simulation tool was used as against the 2D colorimetric images. It is also seen from *Figure 4* that there is significant increase in correct answers for printers B, D, E and F while there is decrease in correct answers for printers A and C, when the 3D simulation was used as against the 2D colorimetric images. The 3D simulation helped increase the accuracy of most observers over the 2D images, some significantly, while it decreased the accuracy of very few observers by very small amount. There was not much change in the observer confidence when making the decision using the two simulations. These results indicate the usefulness of the 3D simulation over the 2D images in getting an increased accuracy, but did not achieve much increase in observer confidence.

The data from the paired comparison experiment were analyzed using Thurstone's Law of Comparative Judgment (Case V).[26] This analysis gives three interval scales of preference for each of the sample sets, namely, the hard copy prints, the 2D images and the 3D simulation. The scales along with the error bars for the three sample sets are shown in *Figure 5*. From the interval scale of 3D simulation shown in *Figure 5*, it is seen that observers judged printers A and C as similar, which could be said as adding to the confusion when observers were doing the identification experiment, which lead to more incorrect answers for these printers compared to the 2D images.

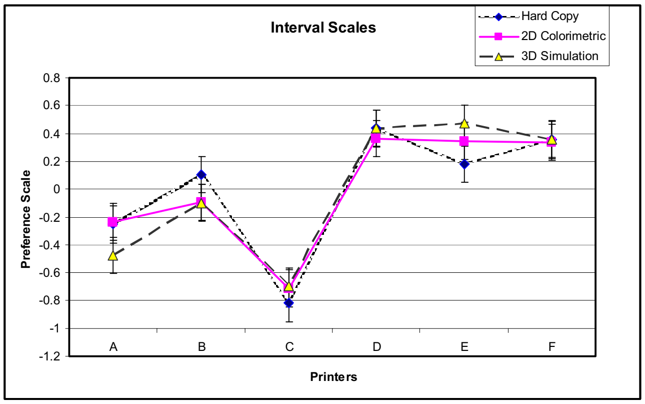

Figure 5. Interval scales of preference for each sample set

A linear fit between the hard copy interval scale and the scale for 2D colorimetric images gave a correlation coefficient of 0.92 and a slope of 0.88. The correlation coefficient of the linear fit between hard copy scale and 3D simulation scale is 0.84 and a slope of 0.99. A correlation coefficient closer to 1 means the two scales have higher correspondence. Ideally, if the 3D simulation is closer in appearance to the actual hard copies, the correlation coefficient between these two scales should be closer to 1 which is not seen in this case. The reasons for this may be attributed to two factors. One is that the simulation included a point light source which gave a sharp specular spot on the 3D simulations, while the actual prints were viewed under diffuse lights. Secondly, it might be due to the fact that observers were not keen enough on using the interactive features of the 3D simulation or in that case even picking up the prints and looking at them from different angles. But a higher slope for the 3D simulation indicated that the scale obtained for it was more spread out, meaning observers were able to distinguish between the 3D simulations more easily than the 2D colorimetric images.

To summarize, results show promise for the 3D simulation while also calling for further investigations and enhancements.

6. Conclusions and Future Enhancements

A display tool was developed to simulate hard copy prints in 3D in a search for an improved soft proofing tool. The procedure followed to develop the tool was described along with the relevant past work. The major components of the workflow were identified as, a simple gloss prediction model and the accurate representation of this gloss on a soft display using computer graphic rendering. The example renderings, give a preliminary idea about the usefulness of the 3D simulation in being able to track the changes in gloss and color.

Two psychophysical experiments were performed to quantify the usefulness of the 3D simulation over current 2D soft proofing technique. The identification experiment indicated an average of 6% increase in accuracy over the 2D images while the paired comparison experiment called for further analysis and investigation.

Certain enhancements the tool could undergo are possible. The first thing to be noted is that the current system requires scanning of the actual print. This might not be desirable for the final soft proofing workflow because the primary purpose is to get an estimation of the final print. This step can be replaced once a better model to estimate the inks and texture properties is available. Also, adding the capability of being able to use different types of light sources might be an important step. The simulation tool renders the images before hand and then assembles them using image based rendering package. Thus it just gives an impression of real time. The next logical step is to make the renderings real time using the advancements in computer graphic hardware and per pixel shading languages. More physically accurate light reflection models like the Cook-Torrance model and Ward model could also be included in the enhancements. To add to the realism of the 3D rendering, more user interaction tools like folding and crumpling of the soft copy are also envisioned. The aim of this study was to develop the foundation for the tool in the simplest possible way to evaluate its usefulness, which is indeed verified by the experimental results, while allowing for more complicated modeling in the future. The modular nature of the simulation workflow allows one to easily incorporate improved components as they become available.

7. Acknowledgements

The authors would like to thank Xerox Corporation, Webster, NY for their financial support and providing the prints. This research was carried out in the Munsell Color Science Laboratory and we express gratitude towards the lab for providing the equipment.

8. References

1. M. H. Bruno, Principles of Color Proofing, M. H. Bruno, 1986.
2. S. L. Fuhs, A study of the subjective differences between soft-copy and hard-copy proofing, M.S. Thesis, Rochester Institute of Technology, 1988.
3. K. C. Williamson, A colorimetric investigation of soft proofing, M.S. Thesis, Rochester Institute of Technology, 1997.
4. A. Masia, R. Holub and J. Gilbert, Requirements for Soft copy Proofing, Proc. of the TAGA, (1985).
5. M. D. Fairchild, Chromatic Adaptation in Hard-copy/Soft-copy comparisons, Proc. SPIE 1912, pg. 14-61 (1993).
6. M. D. Fairchild, Color Appearance Models, Addison Wesley, 1998.

7. G. J. Braun, A Paradigm for Color Gamut Mapping of Pictorial Images, Ph.D. Thesis, Rochester Institute of Technology, 1999.
8. P. Laihanen, Exact Soft Proofing, Journal of Imaging Science and Technology, Vol. 38 No. 5, pg. 432-440 (1994).
9. N. Usui, Print Simulator (the 1st report), Proc. IS&T's 2000 PICS Conference, pg. 177-182 (2000).
10. I. Heikkila, Resolution Management in Image Reproduction: Part II – Simulation of the Resolution Effects, Journal of Imaging Science and Technology, Vol. 45 No. 5, pg. 503–511 (2001).
11. F. W. Billmeyer, Jr., F. X. D. O'Donnell, Visual Gloss Scaling and Multidimensional Scaling Analysis of Painted Specimens, Color Research and Application, Vol. 12 No. 6, pg. 315-326 (1987).
12. R. S. Hunter and R. H. Harold, The Measurement of Appearance, 2nd Edition, John Wiley & Sons, 1987.
13. C. Kuo, Y. Ng and C. J. Wang, Gloss Patch Selection based on Support Vector Regression, IS&T's 2002 PICS Conference, pg. 121-125 (2002).
14. Y. Ng et al, Standardization of Perceptual Based Gloss and Gloss Uniformity for Printing Systems (INCITS W1.1), IS&T's 2003 PICS Conference, pg. 88-93 (2003).
15. E. N. Dalal and K. M. Natale-Hoffman, The Effect of Gloss on Color, Color research and Application, Vol. 24 No. 5, pg. 369-376 (1999).
16. M. Mikula, M. Ceppan and K. Vasko, Gloss and Goniocolorimetry of Printed Materials, Color research and Application, Vol. 28 No. 5, pg. 335-342 (2003).
17. F. Y. Hunt et al, A First Step Towards Photorealistic Rendering of Coated Surfaces and Computer Based Standards of Appearance, Service Life Methodology and Metrology, ACS Symposium Series, Oxford University Press, 2001.
18. S. E. Chen, QuickTime® VR – An Image-Based Approach to Virtual Environment Navigation, ACM SIGGRAPH, pg. 29-38 (1995).
19. ASTM D 523-89, Standard Test Method for Specular gloss, Volume 06.01 of Annual Book of ASTM standards, pg. 36-40, 2003.
20. H. B. Westlund and G. W. Meyer, Applying Appearance Standards to Light Reflection Models, ACM SIGGRAPH, pg. 501-510 (2001).
21. B. T. Phong, Illumination for Computer Generated Pictures, Communication of the ACM, Graphics and Image Processing, Vol. 18 No. 6, pg. 311-317 (1975).
22. J. F. Blinn, Models of Light Reflection for Computer Synthesized Pictures, ACM SIGGRAPH, pg. 192-198 (1977).
23. R. R. Lewis, Making Shaders More Physically Plausible, Computer Graphics Forum, Vol. 13 No. 2, pg. 109-120 (1994).
24. A. Gardner et al, Linear Light Source Reflectometry, ACM SIGGRAPH, Vol. 22 No. 3, pg. 749-758 (2003).
25. P. E. Tobias, J. Ricks and M. Chadwick, Objective, reproducible measurement of printing mottle with a mottle tester, Tappi Journal, Vol. 72 No. 5, pg. 109-112 (1989).
26. L. L. Thurstone, Psychophysical Analysis, Am. J. of Psych., Vol 38, pg. 368-389 (1927).

9. Biography

Rohit A. Patil received his B.Tech. degree in Chemical Technology with specialization in Technology of Fibers and Textile Processing, from Mumbai University Institute of Chemical Technology, India. Currently he is a second year Master's student of Color Science program in Munsell Color Science Laboratory at Rochester Institute of Technology. He has been working with Prof. Mark Fairchild and Dr. Garrett Johnson in the field of color visualization and rendering. He is anticipating his Master's degree in the August of 2004.