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HP 3D Color Gamut – A Reference System for HP's Jet Fusion 580 Color 3D Printers

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Abstract

Designers need to specify the colors for their 3D objects in form of sRGB values, but, given the limitations of the color 3D printing process, they have no idea how those colors chosen on a screen will look once printed in 3D. In addition, HP Inc. wants to showcase the color capabilities of our 3D color printing systems in an effective way.

This paper describes an aesthetically pleasing tool to effectively showcase the color capabilities of our color 3D printing systems.

It is also a reference color system that enables designers 1) to select colors that are achievable with our printing systems, 2) to interactively composite color palettes for their 3D design and 3) to get the desired printed color in a time and cost-efficient way that minimizes iterations. The system itself consists of a series of sub-objects where each sub-object shows how a color looks like when manufactured in different surface orientations. It can be disassembled and used for compositing color palettes for 3D objects, and it is also designed to be manufactured and cleaned fully assembled, showcasing the power of 3D printing.

Introduction

For commercial and industrial 2D printing applications all kinds of tools exist that allow designers to select desired colors on a monitor and get a preview on a monitor or a hard-copy proof of the color appearance of the printed products. Alternatively, they can select a color through a reference system (e.g. Pantone [1] or RAL system [2]) and be assured that high quality Print Service Providers will try to reproduce those colors as accurately as possible given the limitations of the chosen printing systems.

Switching from the mature Graphics Arts world into the relatively new world of color 3D printing, is equivalent to going from a low dimensional space into a higher dimensional space. The overall appearance is now defined not only by the substrate, inks, printing and finishing operations, but by materials, printing agents, printing processes, post-processes and consists of a combination of color, texture, gloss and translucency attributes. Those attributes can obviously be spatially variant.

Thus, the task of communicating to designers how an object will look like once it is 3D printed becomes more challenging. Unlike digital printing, where a hard-copy proof is cheap and easy, 3D printing is still time-consuming and expensive. Thus, tools need to be developed to avoid resource-inefficient try-and-error approaches. This paper tries to address that need in one specific way.

3D Printing Color Technologies and Ecosystems

There are several commercial 3D printing technologies available that produce full-color realistic objects: The Projet CJP 660Pro and the ProJet CJP 860Pro from 3D Systems [3] are two examples that use CMYK inks. Stratasys's J750 [4] has a wide variety of materials that are either transparent or opaque. Mimaki's 3DUJ-553 3D printer [5] uses UV curable inkjet technology. Finally, HP has introduced the HP Jet Fusion 500/300 Series 3D printers [6] to the market, which create full spectrum color parts with a voxel control system resulting in full color functional parts with good mechanical properties. A high reusable CB PA12 material is used for printing.

Several software tools (e.g. Microsoft 3D Builder, AutoCAD's Netfabb, Materialise's Magic and Rhinoceros's Rhino) are available to the designer to generate a 3D model and colorize it and finally save it in a set of different file formats (e.g. obj, 3MF [7]).

Currently, all those file formats require color information to be specified in form of sRGB values. Those sRGB values can be associated with a whole object, portions of an object or a single triangle of it. Objects can also be textured using multi-color images, but in all those cases the color is currently specified in only one color space, which is sRGB. All the software packages have more or less sophisticated rendering algorithms to display a realistic image of the designed object on the screen. None of them currently provides a preview of how on object will look like once it is printed.

3D printing companies obviously show sets of samples, but they generally don't cover the whole color gamut in a systematic way.

HP ships a software package called *HP Smart Stream 3D Build Manager* with HP's 3D Printers. The color editing and preview capabilities are discussed in a YouTube video [8] and in a previous paper [9]. One of the core elements is the *Appearance Reference Object* depicted in Figure 1 and 2. It is a scalable, customizable, patented 3D object that is available through the push of a button in HP's Smart Stream 3D Build Manager. It showcases the color capabilities of HP's 3D color printers on a monitor, in printed and post-processed form.

Figure 1: HP Appearance Reference Object – from the front.

Figure 2: HP Appearance Reference Object – from the back.

Objective

The objective of this paper is to design a reference 3D object that showcases the color capabilities of a 3D printing system in a granularity that goes beyond the primary and secondary colors. Furthermore, this object should enable designers to easily, directly and robustly select the desired colors for their designs eliminating any try-and-error iterative approaches.

Method

The HP 3D Color Gamut allows users to interactively select one or more colors to be used for their specific objects. Once the colors are selected, users can obtain the corresponding sRGB values to be used in their own designs from the reference object. As the reference object is printed on the same type of 3D printing system for which the designers are generating their models, they will robustly get the desired colors.

Our novel reference object design has three main components:
First, there is a clear relationship between the layout of the sub-objects and position of the corresponding colors in the familiar sRGB color cube used by designers.

Second, it has a frame structure that holds the 125 sub-objects in a systematic way and at same time enables individual planes to be separated so that sets of individual sub-objects and individual sub-objects themselves can be easily parsed through in order to closely examine and even remove sub-objects from the structure.

Third, the reference object contains a series of 125 sub-objects that together comprise a granular representation of the color gamut of a 3D printing system. That number gives the user flexibility and yet results in a compact and printable object. The objects are truncated octahedrons providing a series of different surface orientations showcasing any potential color non-uniformity at different surface orientations. The corresponding sRGB values are printed on each sub-object. Overall the reference object is designed to be printed and cleaned as a full assembly for efficiency purposes. However, the hinges of the sub-objects are designed so that the sub-objects can be removed from the 3D structure enabling designers to put together color palettes for a specific design.

Results

The above described design intentions were implemented, and a prototype was printed. The whole object was printed and cleaned in an assembled form (see Fig. 3). Figure 4 shows the object with individual leaves opened so that the designers get access to the colored objects in the interior of the cube.

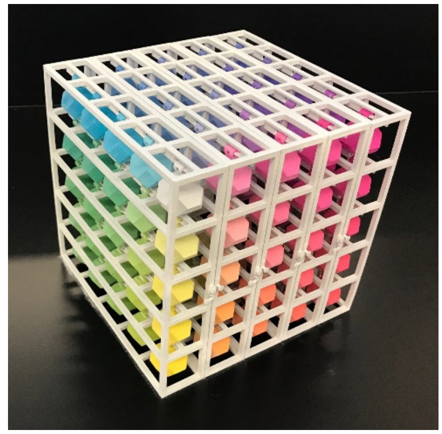

Figure 3: HP 3D Color Gamut after it was printed and cleaned.

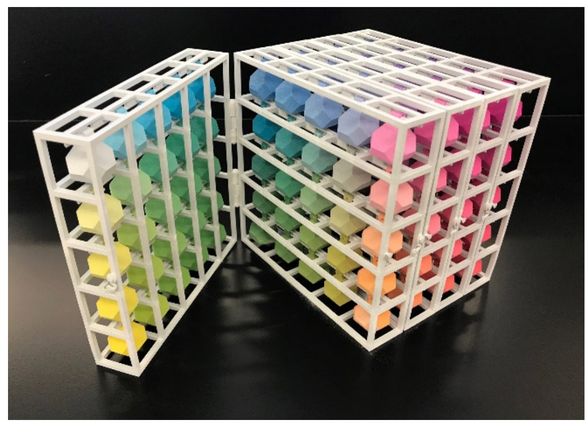

Figure 4: HP 3D Color Gamut with open leaves.

Figure 5 shows a close-up of an individual sub-object. It is based on a truncated octahedron in order to showcase the colors at several different surface orientations (more than 13 orientations). It also shows the design of the hinges that have iteratively been improved to ensure on the one hand that the sub-objects objects don't fall off during cleaning and on the other hand are designed such that they can robustly be removed from the frame itself.

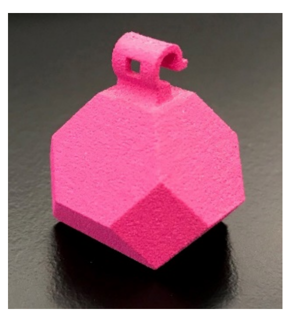

Figure 5: An example of the individual sub-objects.

Figure 6 shows that the sRGB values are depicted at the bottom of the sub-object to communicate the sRGB values needed by the designer to achieve the same color for his/her design. They are placed there in a specific size and font for robust readability. They are also place there to not negatively influence the authentic design of the whole object.

Figure 6: Color values communicating the sRGB values that should be used for 3D objects to achieve the corresponding 3D printed color.

Discussion

The novelty of our work is the following:

- An aesthetically pleasing tool to showcase the color capabilities of color 3D printers
- A reference color system that enables designers
    - To see the range of colors printable with a 3D color printing system, and to give a designer an overall sense of which colors print best
    - To select specific colors that are achievable with a 3D color printing system (hardware, agents, printing modes)
    - To interactively composite color palettes for their 3D objects
    - To get the desired printed colors without an iterative try and error approach
    - To get the color appearance that they want in a time and cost-efficient way
- A compelling example of the production of a complex fully assembled 3D object
- This tool should increase customer success and satisfaction with using our color 3D print technology
- It should raise the brand awareness.

One could ask if it wouldn't be better to specify a color of an object in form of a Pantone or RAL plastic chip specification: The answer to that question is NO and here is the reason behind it: The color gamut of 3D printers is still quite small. Thus, many Pantone colors can't be reproduced and will need to be replaced by a reproducible color. The modification can be quite severe. Furthermore, the technology and materials used for Pantone Plastic sets are injection molding versus 3D printing. Thus, it is preferable to use a reference system that has been produced with the same technology than the to be printed object.

Whether the granularity of the sampling of the sRGB gamut is high enough needs to be determined through tests with designers.

Lastly, how accurate a specific color of the HP color gamut can be reproduced at a different time and with a different printer on the same type needs to be further explored.

Variations

Learnings from presenting the HP Color Gamut at trade shows lead to variations in the design, for example closing the hinges of the sub-object to prevent sub-objects from falling off during shipment and from disappearing during trade shows. We have also increased the robustness of elements (e.g. the front hinges that close the individual leaves for transportation) and made the whole object available in different sizes to suit different use cases.

Some customers are also interested in having their parts post-processed through 3rd party companies to achieve smoother, glossier and more saturated objects. For that purpose, it makes sense to provide a post-processed HP Color gamut that shows what colors can be achieved if a certain sRGB value is used in the design, and where the object is printed and postprocessed. Being able to see the effect of postprocessing for the different colors side-by-side is also a good way to advertise postprocessing.

Currently, the sub-objects have been colorized and labelled manually using commonly used 3D design software packages. It is conceivable to automatize the whole process and enable an easy customization. Models could obviously cover just a portion of the sRGB color space, but at a finer granularity. Or the sampling could be changed to a non-uniform sampling. It all depends on the needs of the people designing objects for 3D printing.

Conclusions

Full-color 3D printing capabilities are still relatively new. Designers are still in the process of learning how to design objects for a 3D printing technology whereby they are efficient and take advantage of the full set of new capabilities. Tools that help them in that process and make their work easier are needed. The HP Color Gamut is one of those tools that try to do that. Time will tell if we succeeded.

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Author Biography

Ingeborg Tastl received her MS in Computer Science from the Vienna University of Technology, Austria (1990) and her PhD in Color Science from *the Vienna University of Technology, Austria (1995). After her Postdoc at ENST in Paris, France, she worked for Sony's Research Lab in San Jose, California (1998-2001). Since 2001 she has worked for HP Inc. Laboratories in Palo Alto, California. Her current research focus is on the appearance capture and reproduction of 3D objects. She has been an active member of IS&T.*

Alex Ju received her BFA in jewelry and metalsmithing from the Rhode Island School of Design (2016). From 2016 until 2019 she worked as a research engineer at first at HP Inc. Laboratories in Palo Alto, CA and then as the Color, Material, and Finish Lead for HP's 3D Business Unit. Her research work encompassed several facets of 3D printing, including applications, experiences, post-processing, and education. She is currently pursuing her MBA at NYU Stern university.

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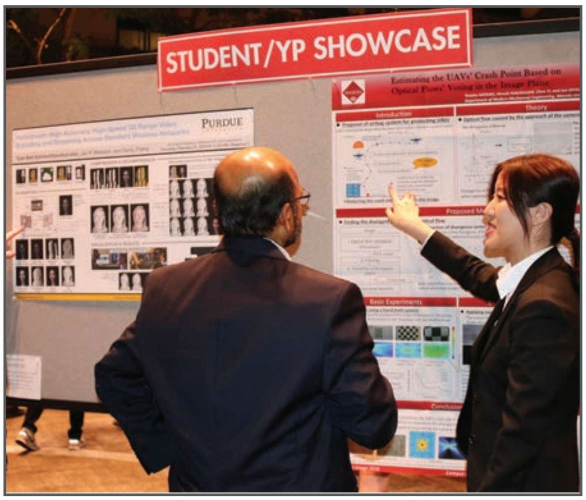

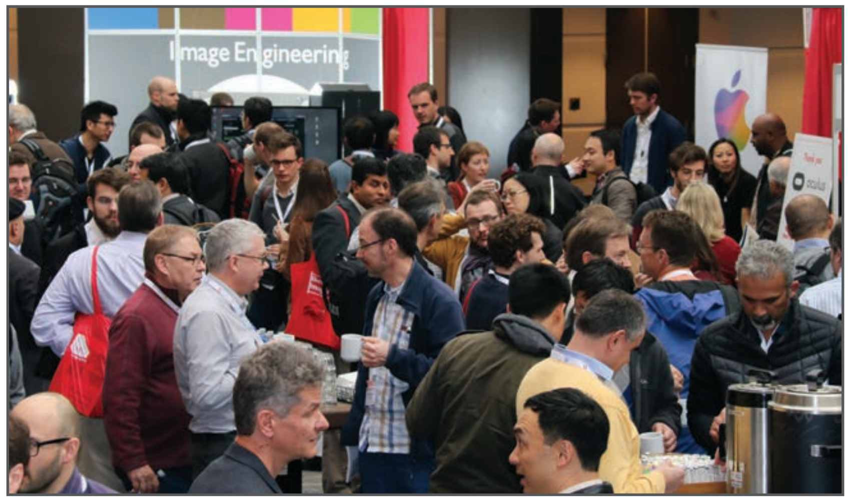

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