Review for

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Creation of Color Analysis Target
Task D: Identify and test an appropriate color pigment system

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Executive Summary

In support of the digitization efforts of the Library of Congress, a solicitation, *Creation of Color Analysis Target*, was issued and subsequently awarded to Avian Rochester, LLC for the design and fabrication of a Next Generation Target (NGT) for color camera calibration. The NGT will be designed to address the shortfalls in commercially available targets. For the purposes of this project, those shortfalls are limited color gamut, and a lack of durability for typical laboratory usage. The lack of durability has a direct impact on the accuracy of the calibrated values for the target. Any physical damage to the target surface requires calibration to reassert the color coordinates for each patch, meaning the cost of operations for a target is directly tied to its durability.

The previous reports, documenting the effort in Tasks A and B of this project, proposed an initial set of colors for inclusion in the NGT. These colors considered existing color targets, color systems of historical importance, as well as the colors of historically relevant materials.

The review for Task C considered which substrate material would be best suited for the NGT. Gloss and color uniformity were investigated, and multiple brands of substrate performed well. The conclusions of that review were to defer the final substrate selection until it can be evaluated in concert with the selected paint system, which is the subject of the present review.

Task D of this project is *Identify and test an appropriate color pigment system*. There are two primary concerns for this task: the attainable distribution of colors and the robustness of the patch surface, in particular the ability to be cleaned.

Task D completes the preliminary investigations of the various aspects of the NGT. With the color distribution, paint system, and base substrate identified, the next step is to produce the approximately 130 colors. After production, a prototype NGT and ultimately the final NGT will be assembled and delivered to the Library of Congress.

Introduction

The scope of this review is to consider the attainable color distribution (gamut) and robustness of a few paint mixing systems.

As with the Task C review, the breadth of this document is therefore narrower than previous reports for this project. What follows will take the form of an experimental report.

Experimental Materials and Analysis

A set of three commercially-available paint mixing systems were identified for testing. Various colors from these systems will be used together to span a larger gamut of colors than would be available to any one system alone.

For an initial evaluation, vendors for each paint system were engaged to create seven mixtures, each based on a specific Munsell color. Five of the colors were highly chromatic, representing the five primary Munsell hues, and two were neutrals. These paints were applied to one of the proposed substrates identified in Task C. As with the paint draw downs described in Task C, a BYK-Gardner byko-drive was used to facilitate consistent draw downs. This device has a vacuum platen to ensure repeatable substrate positioning. A motorized system moves the draw down bar across the surface at a uniform velocity. These features combine to eliminate the human factor and contributes significantly to high quality drawdowns of uniform color and thickness. Towards that end, each paint was drawn down multiple times, yielding a consistent thickness across all paints.

A desirable property of all patches is to have sufficient coverage to approach *complete hiding*, meaning that the paint is fully opaque. Lighter colors typically require a thicker layer to achieve complete hiding. For mechanical reasons related to the final assembly process, it will be necessary to have all colors of the same final thickness. Therefore the lighter paints will be evaluated to determine the required thickness, and all other colors will be applied in that same thickness. Since ultimately the color of each patch will individually measured, it is not a severe problem for any particular patch to not have complete hiding. The effect would be that such a patch might have a slightly different color due to the show-through of the aluminum base.

The initial concept for assembly is shown in Figure 1a below. Using this technique, the paint itself is the top surface of the laminate, and the patch color, gloss, and ability to be cleaned is therefore based on the paint properties alone. After some research into the surface properties of the various paint systems, the decision was made to invert the laminate, placing the paint under the acetate (reference Figure 1b). This has several important advantages. First, the acetate creates a uniform gloss across all patches, regardless of paint systems. Second, the method of cleaning patches is uniform, and again not dependent on the requirements of each individual paint system. Third, the acetate presents a much more durable surface than any of the available paint systems.

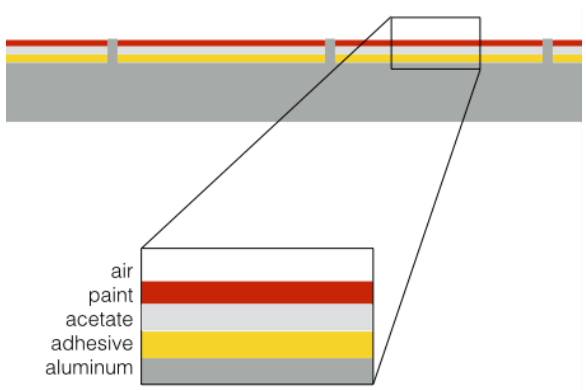

Figure 1a. Schematic of original NGT assembly structure. The top layer is paint, and therefore it defines the gloss level and durability.

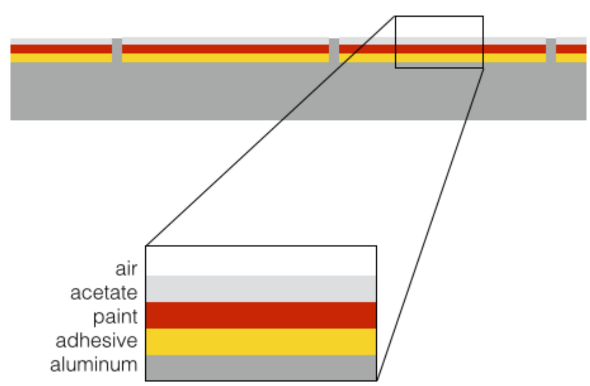

Figure 1b. Schematic of proposed NGT assembly structure. The top layer is acetate, ensuring high and uniform gloss and durability across all patches.

All drawdowns will be evaluated for gloss and color, although the measurements are made with the laminate inverted, and the devices placed on the acetate side. Gloss measurements were made with a BYK-Gardner micro-tri-gloss. This particular device was recently factory certified to be in good working order. It simultaneously measures

20°, 60°, and 85° gloss, all according to ASTM D523 *Standard Test Method for Specular Gloss*. Color measurements were made with a KonicaMinolta FD-7, a bidirectional spectrophotometer. This particular device was also recently factory certified. Color measurements were reported as CIELAB coordinates calculated using illuminant D50 and the CIE 1931 2° standard observer, as specified in CIE Publication 15.2004, *Colorimetry*.

Given the high importance of durability, the final selection of the second-surface assembly requires a verification test of repeated cleaning procedures. The ability to be cleaned (without changing the color) is an important attribute of the NGT. Tables Ia and Ib show the results of color changes resulting from multiple cleaning procedures for 12 patches assembled into the prototype NTG. The final two rows of each column are the mean and standard deviation of each the color differences in that column. Figure 2 shows the patch colors and IDs referenced in the tables.

The second column of Table Ia shows the color difference between the initial condition and after the first cleaning. Column 3 is shows the color difference between after cleaning 1 and after cleaning 2, and so on. Table Ib shows similar data from a second day of testing. The second column in Table Ib shows the color difference between the initial measurements of Day 2 (prior to any cleaning) and the final condition of Table Ia, after the fifth cleaning.

Figure 2. Patch IDs of the colors measured for the cleaning test.

Table Ia. Color differences of each patch when compared to the previous condition.

Patch ID	Day 1				
	ΔE*ab after 1st cleaning	ΔE*ab after 2nd cleaning	ΔE*ab after 3rd cleaning	ΔE*ab after 4th cleaning	ΔE*ab after 5th cleaning
1	1.30	0.38	0.26	0.23	0.16
2	0.24	0.06	0.13	0.05	0.08
3	0.36	0.05	0.27	0.04	0.11
4	0.35	0.24	0.09	0.07	0.03
5	0.96	0.66	0.05	0.07	0.09
6	0.20	0.15	0.14	0.06	0.15
7	1.40	0.95	0.06	0.05	0.18
8	1.94	0.79	0.44	0.14	0.08
9	0.26	0.29	0.09	0.06	0.03
10	0.33	0.10	0.12	0.05	0.10
11	0.33	0.22	0.04	0.05	0.03
12	0.23	0.33	0.06	0.12	0.06
mean	0.66	0.35	0.14	0.08	0.09
std dev	0.59	0.30	0.12	0.06	0.05

Table Ib. Color differences of each patch when compared to the previous condition.

Patch ID	Day 2					
	ΔE*ab after 5th cleaning	ΔE*ab after 6th cleaning	ΔE*ab after 7th cleaning	ΔE*ab after 8th cleaning	ΔE*ab after 9th cleaning	ΔE*ab after 10th cleaning
1	0.63	0.17	0.14	0.03	0.03	0.16
2	0.09	0.38	0.11	0.09	0.08	0.05
3	0.04	0.24	0.10	0.18	0.15	0.01
4	0.08	0.03	0.14	0.04	0.05	0.01
5	0.19	0.25	0.09	0.17	0.20	0.10
6	0.21	0.26	0.17	0.17	0.10	0.02
7	0.19	0.10	0.19	0.01	0.16	0.21
8	0.21	0.31	0.09	0.12	0.24	0.44
9	0.05	0.09	0.08	0.04	0.08	0.04
10	0.07	0.05	0.11	0.05	0.02	0.04
11	0.11	0.07	0.07	0.04	0.01	0.04
12	0.03	0.22	0.28	0.08	0.33	0.25
mean	0.16	0.18	0.13	0.08	0.12	0.11
std dev	0.16	0.11	0.06	0.06	0.10	0.13

Table Ia show a consistent reduction in color difference as compared to the first five cleanings. It seems that there is some type of coating or release agent that requires a few attempts to fully remove. After the third cleaning, the mean color differences are quite small, and stay small even with the continued experiment on day 2.

To quantify gloss consistency vs cleaning, a second cleaning experiment was performed on whole acetate sheets. (The gloss meter requires an area larger than the 0.5" patches in the prototype target.) The specific sheet selected was a green paint from vendor C. The general procedure was the same: measure the uncleaned surface, clean, measure, and repeat. Each point in the plots below is based on n=10 measurements taken across the sheet. Mean results are in Figure 3, and the standard deviation of the 10 measurements is in Figure 4.

All three gloss angles seem to converge on about 100 gloss units after cleaning ten times. The high early standard deviation is an indication that one side of the sheet cleaned sooner or more easily, and so converged to the final gloss with fewer cleanings. The conclusion is that as with the color measurements, five thorough cleanings are required to stabilize the surface. Note importantly that these required cleanings will take place at Avian Rochester, prior to the delivery of the final NGT assembles.

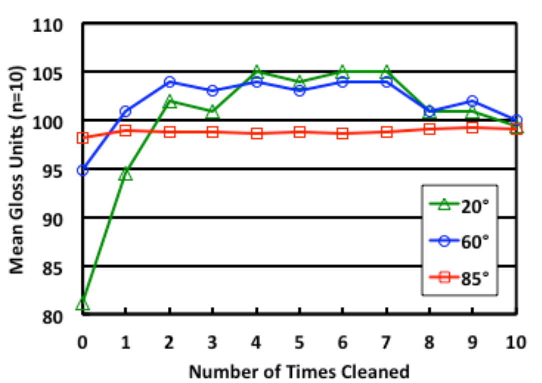

Figure 3. Mean gloss results after repeated cleaning.

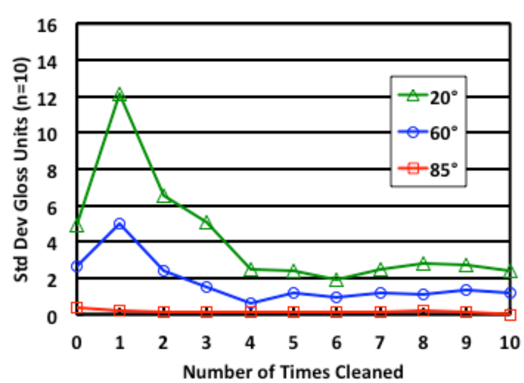

Figure 4. Standard deviation of ten measurements after repeated cleaning.

Final Assembly Conclusions

As shown in Fig 1b, the optimum assembly method is to invert the paint/acetate laminate, placing the paint layer underneath the acetate. There are several details that were verified for enable this decision:

- The adhesive layer now falls between the paint and the aluminum. The paint adheres very well to the adhesive tape, and will hold as well as the acetate/adhesive bond.
- After a few (five) initial cleanings, the first surface acetate can be cleaned without affecting the color or gloss of the laminate.
- The second-surface optical contact between paint and acetate creates a uniform gloss level for all patches, regardless of the type of paint.

Paint System Considerations

The strengths of each paint system (with respect to attainable color gamut) will be combined to create a better color distribution than could be attained with any individual paint system. Using the seven test colors described above, the maximum chroma of each paint system in each of the five Munsell primary hues was evaluated. As should be expected, different systems achieve higher chroma in different regions. Using the proposed distribution of colors described in the Task A (general colors) and Task B (heritage colors) reports, we considered which system could best produce each particular color. The difficulty lies only in the high-chroma regions. A single system will be selected for the whole of the central portion of the gamut. While any of the paint systems could satisfy the requirements of the low-chroma region, we selected Vendor A for three reasons: cost, availability, and demonstrated vendor cooperation in the past. However, each system will be needed for some region of the color gamut.

The chromatic paint vendors are identified in the Appendix by code. All are national brands available in the Rochester NY area. Neutral colors (not listed) will be evenly spaced in L* from the minimum to the maximum for the available achromatic formulations. Note that the best match Munsell colors were selected from a color set that were separated by steps of two chroma units. Hence some of the estimated color differences from the target CIELAB coordinates are greater than 5 units (although none are greater than 10). We feel that these will still create the desired overall color distribution. If by chance two colors are too close, we will reformulate one or both.

The neutral colors represent important aspects of the NGT, with the lowest D50/2° chroma possible being desirable for neutrals.[†] Vendor A has the facilities to permit an iterative approach to neutral formulation. Starting with the computer match, the chroma of each of the 20 neutrals will be individually minimized to C* of 2 units maximum, with the target being 1 unit.

Conclusions and Next Steps

Three paint systems have been identified and are anticipated to be able to produce the NGT colors proposed in the Task A and Task B reports. The assembly procedure placing the acetate on the top of the paint laminate has been shown to meet the robustness requirements of the NGT; repeated cleaning showed to minimal affect the color and gloss of the patches.

The next phase of the project is to formulate colors for all patches, and create draw-downs of these colors. From those physical color patches the prototype NGT will be assembled and delivered to LC for final comments and approval.

[†] Anecdotal reports at the 2016 IS&T Archiving conference indicated that the maximum permissible CIELAB C* of target neutrals is 2 units. Preliminary indications are that NGT neutrals will have C* of 1 unit at most.

Appendix: Proposed CIELAB for chromatic patches, best match Munsell color, degree of match, and vendor code.

Patch ID	Target CIELAB Color				Best Match Munsell			Match ΔE*ab	Vendor Code
	L*	a*	b*	C*	H	V	C		
1	20	-25	0	25.0	10G	2	6	3.4	A
2	20	-10	0	10.0	2.5BG	2	2	2.1	A
3	20	0	-25	25.0	5PB	2	6	3.4	A
4	20	0	-10	10.0	5PB	2	2	0.4	A
5	20	0	10	10.0	7.5Y	2	2	2.2	A
6	20	2	5	5.4	7.5YR	2	2	7.0	A
7	20	10	0	10.0	10RP	2	2	1.2	A
8	20	15	10	18.0	10R	2	4	4.3	A
9	20	25	0	25.0	10RP	2	6	3.4	A
10	30	-25	-25	35.4	5B	3	6	4.5	C
11	30	-25	25	35.4	10GY	3	6	4.0	C
12	30	-12	-12	17.0	5B	3	4	4.4	A
13	30	-12	12	17.0	10GY	3	4	5.5	A
14	30	0	-55	55.0	5PB	3	12	1.2	B
15	30	0	-20	20.0	5PB	3	4	0.7	A
16	30	2	5	5.4	7.5YR	3	2	8.2	A
17	30	12	-12	17.0	5P	3	4	4.3	A
18	30	12	12	17.0	2.5YR	3	2	4.0	A
19	30	15	17	22.7	2.5YR	3	4	2.6	A
20	30	25	25	35.4	2.5YR	3	6	2.4	A
21	30	30	-30	42.4	5P	3	8	3.5	B
22	30	50	0	50.0	7.5RP	3	10	3.0	B
23	40	-35	0	35.0	2.5BG	4	6	3.0	C
24	40	-30	-30	42.4	5B	4	8	1.6	C
25	40	-25	30	39.1	7.5GY	4	6	2.5	A
26	40	-17.5	0	17.5	2.5BG	4	4	4.3	A
27	40	0	-45	45.0	5PB	4	10	2.5	B
28	40	0	-22.5	22.5	5PB	4	6	4.0	A
29	40	0	10	10.0	5Y	4	2	5.3	A
30	40	0	22.5	22.5	5Y	4	2	7.6	A
31	40	0	45	45.0	7.5Y	4	6	2.4	C
32	40	10	20	22.4	5YR	4	4	5.2	A
33	40	27.5	0	27.5	7.5RP	4	6	2.0	A
34	40	30	-20	36.1	7.5P	4	8	2.5	A
35	40	30	20	36.1	7.5R	4	6	3.5	A
36	40	40	-40	56.6	5P	4	12	3.7	B
37	40	40	40	56.6	10R	4	10	2.4	B
38	40	50	25	55.9	5R	4	12	4.5	B
39	40	55	0	55.0	7.5RP	4	12	1.7	B
40	50	-45	0	45.0	2.5BG	5	8	2.5	A

Patch ID	Target CIELAB Color				Best Match Munsell			Match ΔE*ab	Vendor Code
	L*	a*	b*	C*	H	V	C		
41	50	-35	-35	49.5	5B	5	10	0.9	C
42	50	-35	45	57.0	7.5GY	5	8	6.5	C
43	50	-17.5	-17.5	24.7	5B	5	6	4.8	A
44	50	-17.5	22.5	28.5	7.5GY	5	4	3.8	A
45	50	0	-50	50.0	5PB	5	12	3.6	B
46	50	0	10	10.0	2.5Y	5	2	5.2	A
47	50	0	60	60.0	7.5Y	5	8	3.3	B
48	50	10	20	22.4	5YR	5	4	4.0	A
49	50	10	35	36.4	10YR	5	6	6.0	A
50	50	17.5	-17.5	24.7	5P	5	6	2.2	A
51	50	25	25	35.4	10R	5	6	2.8	A
52	50	35	-35	49.5	5P	5	12	2.4	B
53	50	40	0	40.0	7.5RP	5	8	4.6	A
54	50	50	25	55.9	5R	5	12	5.2	B
55	50	50	50	70.7	10R	5	12	3.2	B
56	50	60	0	60.0	7.5RP	5	14	3.2	C
57	60	-45	0	45.0	2.5BG	6	8	2.3	C
58	60	-45	45	63.6	10GY	6	10	3.9	C
59	60	-30	-30	42.4	5B	6	8	3.4	C
60	60	-25	30	39.1	7.5GY	6	6	3.5	C
61	60	-22.5	0	22.5	2.5BG	6	4	1.7	A
62	60	0	-35	35.0	5PB	6	8	3.6	A
63	60	0	-17.5	17.5	5PB	6	4	3.1	A
64	60	0	22.5	22.5	5Y	6	2	7.2	A
65	60	0	60	60.0	5Y	6	8	3.4	C
66	60	5	10	11.2	5YR	6	2	2.7	A
67	60	5	20	20.6	2.5Y	6	2	6.4	A
68	60	5	30	30.4	2.5Y	6	4	2.8	A
69	60	25	-25	35.4	5P	6	8	3.8	A
70	60	25	25	35.4	10R	6	6	3.4	A
71	60	27.5	0	27.5	7.5RP	6	6	3.2	A
72	60	35	60	69.5	2.5YR	6	12	6.8	B
73	60	40	35	53.2	10R	6	10	5.2	B
74	60	45	0	45.0	7.5RP	6	10	4.5	C
75	70	-45	0	45.0	2.5BG	7	8	2.8	C
76	70	-40	50	64.0	7.5GY	7	10	6.4	C
77	70	-22	-22	31.1	5B	7	6	3.3	A
78	70	-20	25	32.0	7.5GY	7	4	5.4	A
79	70	0	-30	30.0	5PB	7	8	4.8	A
80	70	0	50	50.0	5Y	7	6	5.6	C

Patch ID	Target CIELAB Color				Best Match Munsell			Match ΔE*ab	Vendor Code
	L*	a*	b*	C*	H	V	C		
81	70	0	80	80.0	7.5Y	7	10	6.1	C
82	70	5	20	20.6	2.5Y	7	2	6.3	A
83	70	15	25	29.2	7.5YR	7	4	5.1	A
84	70	15	40	42.7	7.5YR	7	6	4.7	A
85	70	25	-25	35.4	5P	7	8	4.7	A
86	70	30	50	58.3	5YR	7	10	4.8	B
87	70	35	0	35.0	5RP	7	8	2.9	A
88	80	-35	0	35.0	2.5BG	8	6	2.6	B
89	80	-30	40	50.0	7.5GY	8	8	5.1	C
90	80	-17.5	0	17.5	5BG	8	4	5.3	A
91	80	0	-16	16.0	7.5PB	8	4	2.2	A
92	80	0	10	10.0	10YR	8	2	5.3	A
93	80	0	40	40.0	5Y	8	6	5.5	C
94	80	0	60	60.0	5Y	8	8	2.1	C
95	80	0	80	80.0	5Y	8	10	6.5	B
96	80	5	10	11.2	5YR	8	2	1.7	A
97	80	5	25	25.5	10YR	8	4	3.0	A
98	80	20	30	36.1	2.5YR	8	6	3.3	A
99	80	25	0	25.0	5RP	8	6	1.8	A
100	90	-5	0	5.0	7.5B	9	2	5.7	A
101	90	0	-5	5.0	7.5PB	9	2	1.3	A
102	90	0	5	5.0	2.5R	9	2	6.3	A
103	90	0	50	50.0	5Y	9	6	3.9	B
104	90	2	10	10.2	5YR	9	2	3.9	B
105	90	5	0	5.0	5RP	9	2	1.2	A