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Evaluating the use of mixed NPs (measured and estimated) in SN and YNSN model

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Outline

- Introduction & Problem Description
- Experimental Methods
- Results & Conclusion
- Future Work
- References

Introduction & Problem Description

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- **Print reproductions**
  - the problem of **metamerism** → **spectral** color reproduction.
- **Dot gain effect**
  - **Mechanical**
    - ink absorbing (spreading out) into (onto) the paper.
  - **Optical**
    - exitance of diffused light from the edge of the dot seems like reflected light beyond the edge.

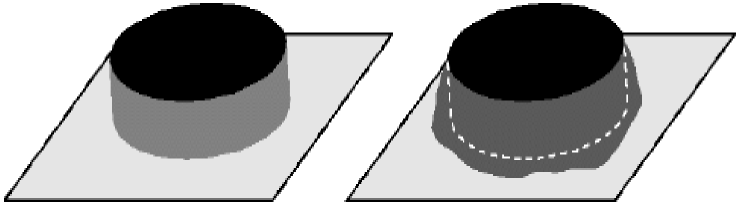

Fig. 1: The theoretical (left) and real (right) dot

Experimental Methods (1)

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- **Spectral printer modeling**
- **Neugebauer (SN) Model**

  The convex combination of n reflectances of Neugebauer primaries

$$\hat{r}(\lambda) = \sum_{i=0}^{2^m-1} w_i r_{i,\max}(\lambda)$$

$$w_i \in [0,1], \sum_{i=0}^{2^m-1} w_i = 1$$

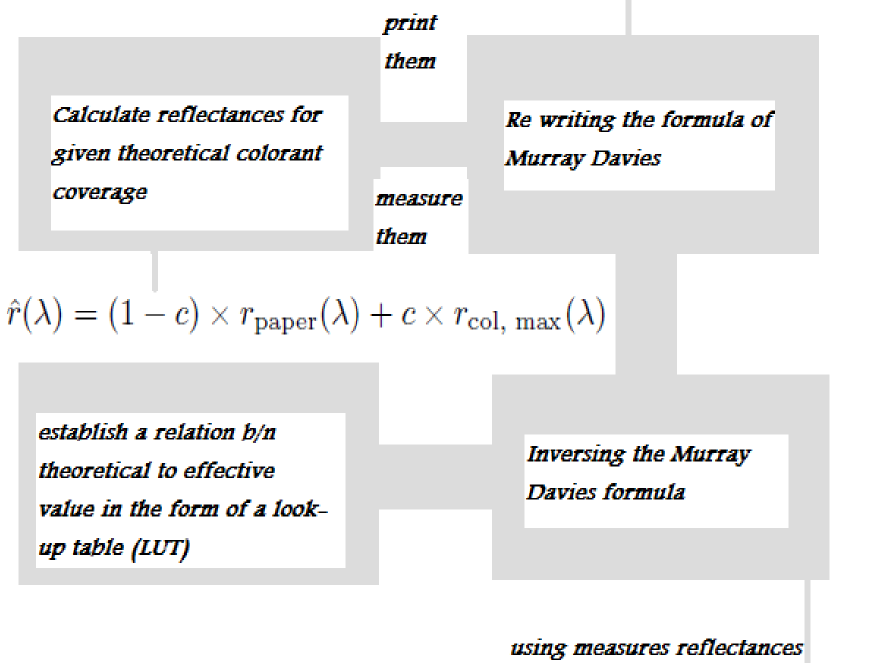
- where $r_i(\lambda)$ is the spectral reflectance and w_i is the area of coverage of the i^{th} primaries,
- the primary reflectances

  $\{r_i(\lambda)\}_{i=1}^{16}$

  for four channel (CMYK) printer.

- Look up table (LUT) for effective colorant coverage

$$r_{\text{meas}}(\lambda) = (1 - a_{\text{eff}}) \times r_{\text{paper}}(\lambda) + a_{\text{eff}} \times r_{\text{col, max}}(\lambda)$$



$$\hat{r}(\lambda) = (1 - c) \times r_{\text{paper}}(\lambda) + c \times r_{\text{col, max}}(\lambda)$$

$$a_{\text{eff}} = \frac{r_{\text{meas}}(\lambda) - r_{\text{paper}}(\lambda)}{r_{\text{col, max}}(\lambda) - r_{\text{paper}}(\lambda)}$$

Experimental Methods (2)

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- **Spectral printer modeling**
- **Yule-Nielsen modified spectral Neugebauer (YNSN) model**
  - adding empirical correction Yules-Nielsen *n* factor – to incorporate the optical dot gain effect in the spectral printer model.

$$\hat{r}^{1/n}(\lambda) = \sum_{i=0}^{2^m-1} w_i r_{i,\max}^{1/n}(\lambda).$$

- **Neugebauer primaries (NPs)**
  - 4 channel printer → 16 NPs (2^4)
  - **measured**,
  - **estimated (**Kubelka-Munk model),
  - **mixed** (combination of measured and estimated) NPs**.**

Experimental Methods (3)

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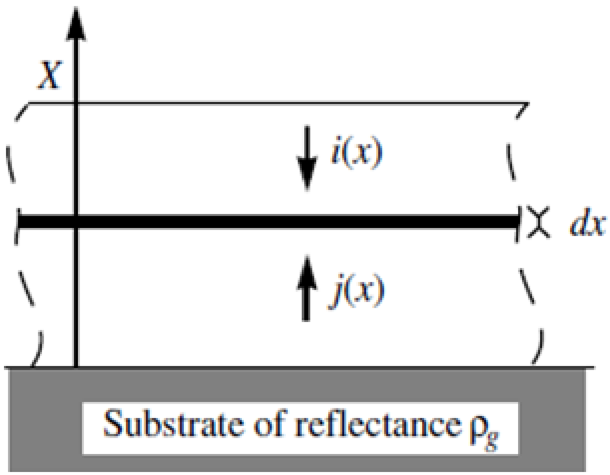
- **Kubelka–Munk theory (two flux model)**



Source: Digital Color Imaging Handbook

- Two fluxes are considered
  - *i(x)* oriented downward,
  - *j(x)* oriented upward.

- Light absorbing and light scattering ink of thickness *X* in contact with a paper of reflectance ρ_g

$$\begin{cases} \dfrac{d\,i(x)}{dx} = (K+S)\,i(x) - S\,j(x) \\ \dfrac{d\,j(x)}{dx} = -(K+S)\,j(x) + S\,i(x) \end{cases}$$

  - *K* – the phenomenological absorption coefficient
  - *S* – the phenomenological scattering coefficient

$$\begin{bmatrix} \dfrac{d\,i(x)}{dx} \\ \dfrac{d\,j(x)}{dx} \end{bmatrix} = \begin{bmatrix} K+S & -S \\ S & -(K+S) \end{bmatrix} \cdot \begin{bmatrix} i(x) \\ j(x) \end{bmatrix}$$

Experimental Methods (4)

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- Compute **K/S ratio**:
  - of the paper,
  - for each colorant independently,
  - for the combinations:

    $(\mathbf{K/S})_{\mathbf{mixture}} = \mathbf{a(K/S)}_{\mathbf{colorant1}} +$
    $+ \mathbf{b(K/S)}_{\mathbf{colorant2}} \ldots + (\mathbf{K/S})_{\mathbf{paper}},$
    where a, b,… are the areas of coverage

→ compute **reflectances**

$$R_\infty(\lambda) = 1 + \frac{K(\lambda)}{S(\lambda)} - \sqrt{\left(\frac{K(\lambda)}{S(\lambda)}\right)^2 + 2\left(\frac{K(\lambda)}{S(\lambda)}\right)}$$

- measured (M), estimated (E) and mixed **NPs**
- found out the best combination of M and E NPs,
- the combination of NPs:
  - 4 channel printer → 16 NPs (2^4)
  - MNPs + ENPs (in KM model always first 5 NPs are always measured),
  - 5 MNPs + 11 combination of M and ENPs,
  - binary words to modelize the combinations: $\mathbf{2^{11} = 2048}$ combinations of M and E NPs.

Experimental Results & Conclusion (1)

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- Tab. 1: Spectral and colorimetric differences for 7 the best and 7 the worst results by using SN model and the combination of Xerox laser printer and color copy paper:

No of NPs	RMSE		GFC		ΔE		ΔE94	
	Average	***Std.***	***Average***	***Std.***	***Average***	***Std.***	***Average***	***Std.***
240	0.0362	0.0250	0.9940	0.0077	**6.6121**	4.0286	4.6232	2.6802
176	0.0359	0.0248	0.9940	0.0077	6.6176	4.0179	4.6185	2.6708
208	0.0356	0.0247	0.9939	0.0078	6.6176	4.0353	4.5671	2.6291
144	0.0354	0.0244	0.9939	0.0078	6.6251	4.0246	4.5633	2.6210
488	0.0365	0.0249	0.9944	0.0074	6.6286	4.0097	4.6846	2.6553
232	0.0364	0.0248	0.9942	0.0075	6.6295	4.0234	4.6750	2.6837
456	0.0359	0.0245	0.9943	0.0075	6.6336	4.0159	4.6270	2.6055
...	...	...	...	...	...	...	...	...
1845	0.0384	0.0246	0.9938	0.0090	8.4609	5.0221	5.7338	2.8985
1841	0.0383	0.0246	0.9937	0.0089	8.4631	4.9709	5.7276	2.8780
1813	0.0378	0.0244	0.9937	0.0091	8.4679	5.0167	5.6814	2.8748
1557	0.0376	0.0244	0.9936	0.0091	8.4688	5.0320	5.6736	2.9047
1809	0.0377	0.0234	0.9935	0.0090	8.4816	4.9666	5.6805	2.8545
1585	0.0382	0.0244	0.9935	0.0090	8.4949	4.9601	5.7532	2.8807
1553	0.0377	0.0241	0.9934	0.0090	8.5147	4.9553	5.7081	2.8571

Experimental Results & Conclusion (2)

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- Tab. 2: The best 7 and the worst 7 results for combination of **mixed NPs** (measured 0 and estimated 1) in binary words to modelize the combinations in context of the result showed in Tab. 1

NPs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
240	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1
176	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1
208	0	0	0	0	0	0	0	0	1	1	0	0	1	1	1	1
144	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1
488	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	1
232	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	1
456	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	1
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1845	0	0	0	0	0	1	1	1	0	0	1	1	0	1	0	0
1841	0	0	0	0	0	1	1	1	0	0	1	1	0	0	0	0
1813	0	0	0	0	0	1	1	1	0	0	0	1	0	1	0	0
1557	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0
1809	0	0	0	0	0	1	1	1	0	0	0	1	0	0	0	0
1585	0	0	0	0	0	1	1	0	0	0	1	1	0	0	0	0
1553	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0

Experimental Results & Conclusion (3)

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- Tab. 3: Spectral and colorimetric difference for NG model and the combination of Xerox laser printer and color copy paper:
  - the comparison of three results (***measured – M***, ***estimated – E*** and the best result of **mixed** NPs)

No of NPs	**RMSE**		**GFC**		**ΔE**		**ΔE94**	
	Average	***Std.***	***Average***	***Std.***	***Average***	***Std.***	***Average***	***Std.***
M (1)	0.0390	0.0252	0.9942	0.0073	7.8647	4.9943	5.3988	2.8342
E (2048)	0.0388	0.0232	0.9930	0.0096	7.3620	4.1392	5.0476	2.7246
240	0.0362	0.0250	0.9940	0.0077	**6.6121**	4.0286	4.6232	2.6802

Experimental Results & Conclusion (4)

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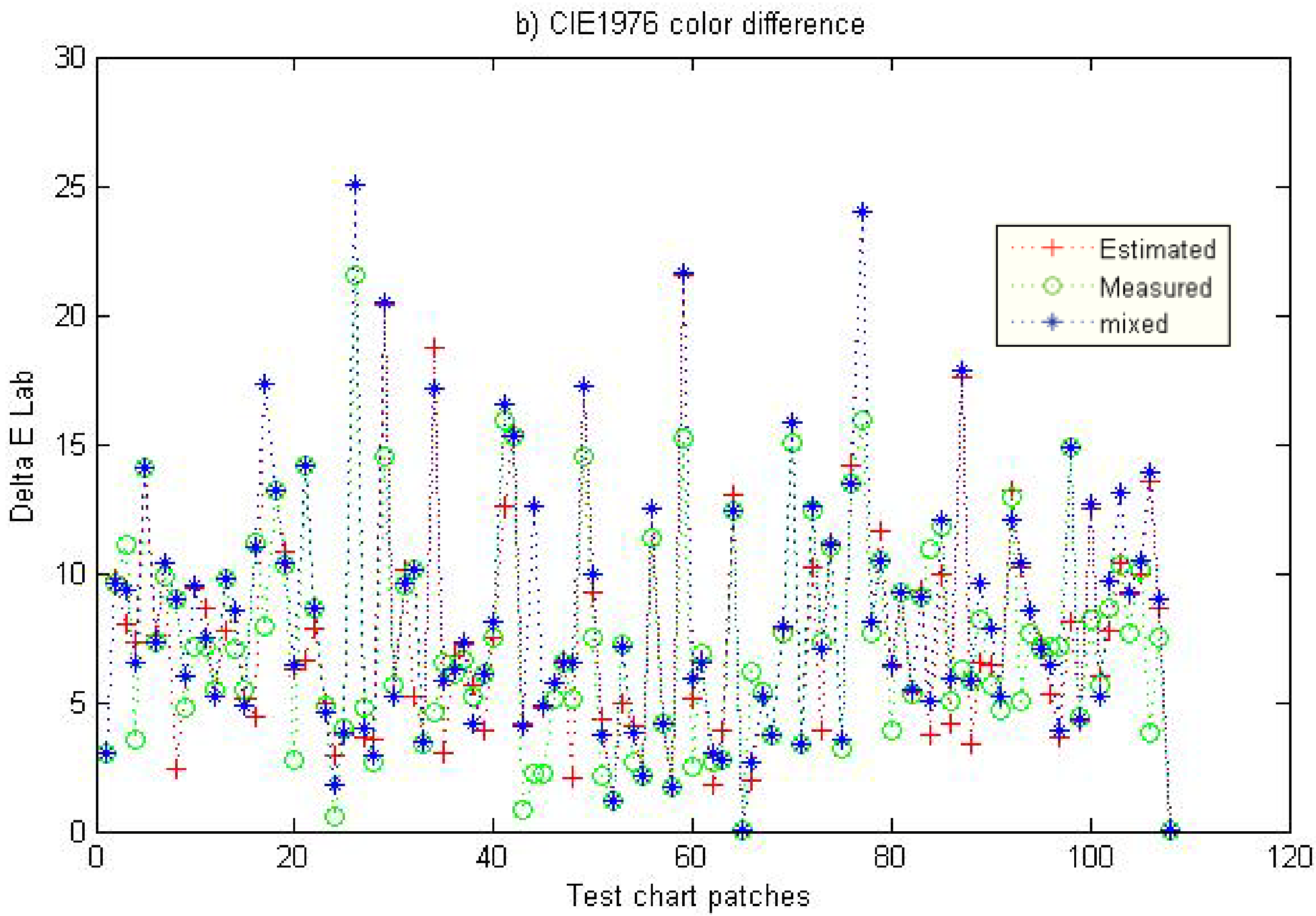

Experimental Results & Conclusion (4)

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- The main question: The best combination of MNPs and ENPs for specific combination of the printer and paper,
- testing the combination of Xerox Phaser 7760 color laser printer and color copy paper (grammage: 250 g/m^2, opacity: 99.5077),
- finding the way to print out NPs for printers with high number of channels (SDK and direct communication with printer is required) – 6 channel printer (2^6 = 64 NPs),
- our investigations are of the typical importance for the printing industry as it tries to explore the possibility of using the appropriate paper quality in order to obtain the optimal print from the specific printers.

Future Work

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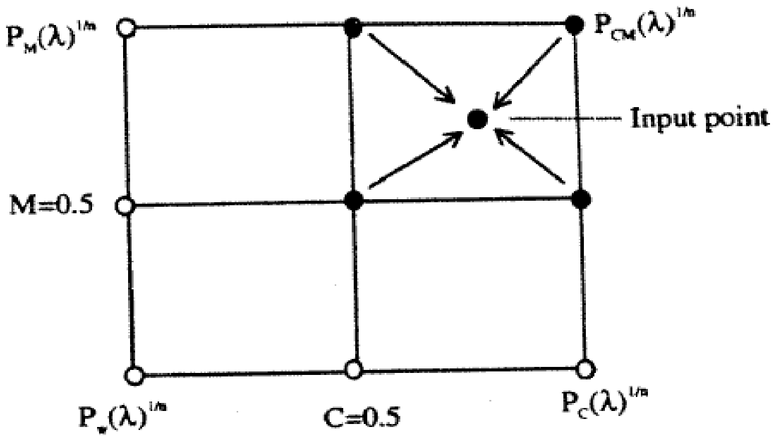
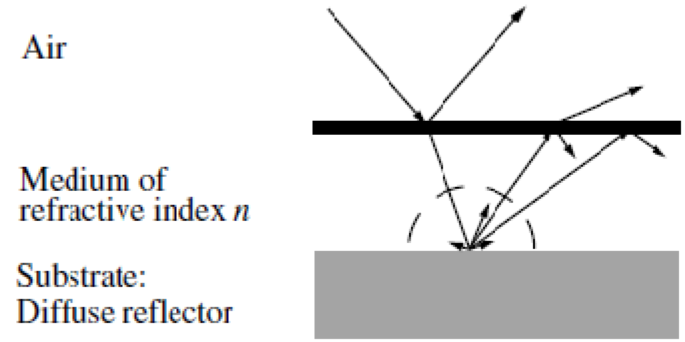
- Increase the accuracy of the spectral printer model estimations
- **Cellular SN model**



- Illustration of cellular SN model of two channel printer (cyan and magenta), Source: Balasubramanian, 1999

- influence of **fluorescence** – to predict the behavior of a transparent medium containing fluorescent molecules,
- improving **KM theory**
  - to incorporate the real interactions between the media and the colorant layers,
  - Saunderson correction.



- Surface reflection and multiple internal reflections, Source: Digital Color Imaging Handbook (Sharma, 2003)

References

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- Abebe, Mekides. Kubelka-Munk Theory for Efficient Spectral Printer Modeling, 2010, Master thesis
- J. A. C. Yule and W. J. Nielsen, “The penetration of light into paper and its effect on halftone reproduction,” in *TAGA Proc.*, May 1951, pp. 65–76.
- R. Balasubramanian, “Colorimetric modeling of binary color printers,” in *Proc. IEEE Intl. Conference on Image Proc.*, Nov. 1995, vol. II, pp. 327–330.
- Abebe, Mekides, Gerthardt Jérémie, Hardeberg, Y., Jon. Kubelka-Munk Theory for Efficient Spectral Printer Modeling, EI 2010
- SHARMA, Gaurav. *Digital Color Imaging Handbook*. CRC Press LLC, 2003. 780 p. ISBN 0-8493-0990-x

Thank you for your attention !

Any question or suggestion ?