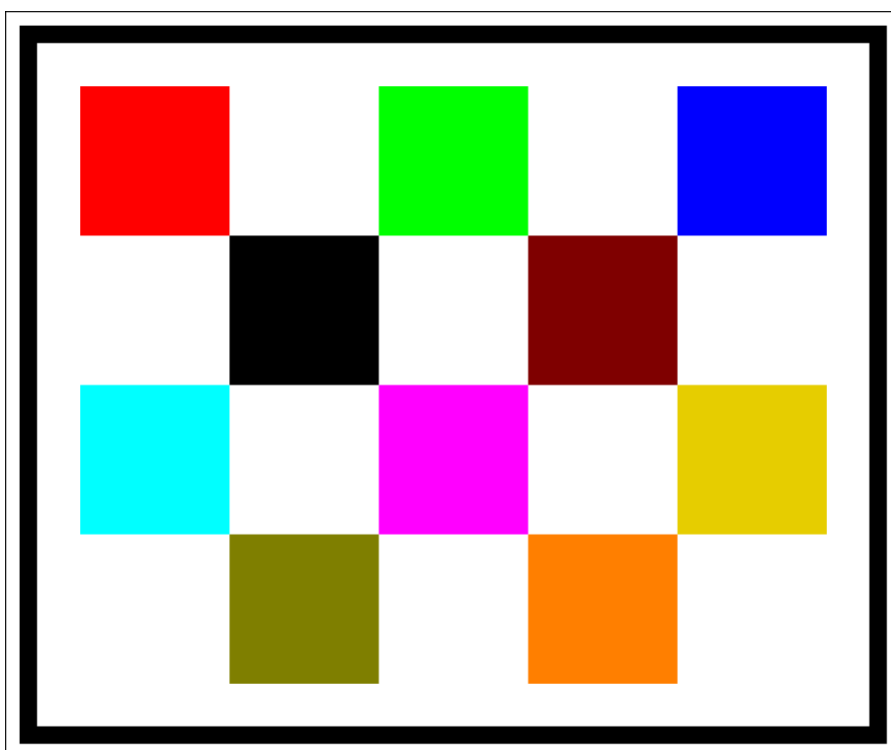


Introduction

- In image based dietary assessment, color is a very important feature in food identification.
- To eliminate the influence of varying lighting conditions and mitigate variations in camera sensor response, color calibration is required prior to food classification.
- We have designed a color checkerboard pattern or fiducial marker (FM) to be included in the scene to serve as reference for estimation of scale and pose of food items and to provide reference information for color calibration.



- In our previous user studies we have generated and distributed FMs to participants. We need to develop methods such that participants can generate their own FMs.

Color Correction

- Our approach for color correction is based on the von-Kries model.
- A $M \times 3$ color reference matrix for color calibration is denoted as C_{ref} , where $M = 11$ is the number of checkerboard colors is constructed under the CIE standard illuminant D65.
- The color matrix denoted as C_{test} is constructed similar to C_{ref} , for an image to be corrected under the lighting condition of the scene.
- The 3×3 color correction matrix D is estimated by:

$$\hat{D} = \arg \min_{D \in \mathbb{R}^{3 \times 3}} \sum_{j=1}^M \|(C_{refj})^t - D(C_{testj})^t\|^2$$

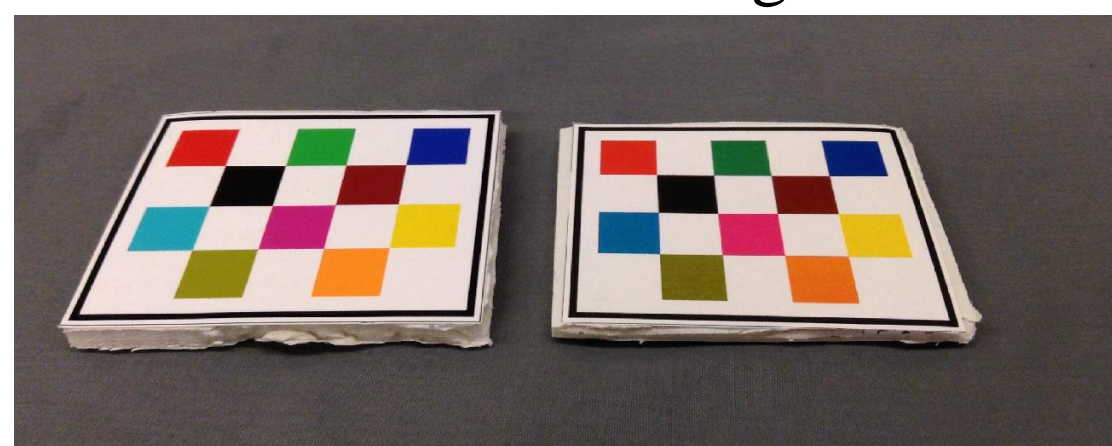
where C_{refj} and C_{testj} are the RGB color vector associated with j^{th} color.

- Colors can be then calibrated using the linear mapping.

$$C_{corrected}^t = \hat{D}C_{original}^t$$

Printer Indexing System

- Reproducing exact colors on various printers is a difficult problem. To properly color calibrate an image, we must determine which printer was used to print the FM included in the image. We call this printer indexing.



- We design our indexing system by associating each printer with an FM that has different color square arrangements.
- Denote i as the index for the i^{th} printer and its corresponding printer color reference matrix is $C_{ref}^{(i)}$.
- The normalized cross correlation (NCC) score is used to estimate the printer index.
- The NCC score is obtained based on the vectorized color matrix:

$$f(C_{test}, C_{ref}^{(i)}) = \frac{1}{3 \cdot M - 1} \frac{\sum_{k=1}^{3 \cdot M} \{(C_{test}(k) - \mu_{C_{test}})(C_{ref}^{(i)}(k) - \mu_{C_{ref}^{(i)}})\}}{\sigma_{C_{test}} \sigma_{C_{ref}^{(i)}}}$$

- The correct printer index i is estimated, out of total N printers:

$$\hat{i} = \arg \max_{i \in \{1, \dots, N\}} \{f(C_{test}, C_{ref}^{(i)})\}$$

- The correct color calibration matrix can then be used to color correct the image.

Error Control Using Binarized Marks

- From our experiment we observed that similar FM colors (such as red, orange and brown) may be difficult to differentiate under different lighting conditions.
- For error control, we use “binarized marks”.
- Binarized marks are combinations of small black squares placed at the center of one or more squares of the FM.



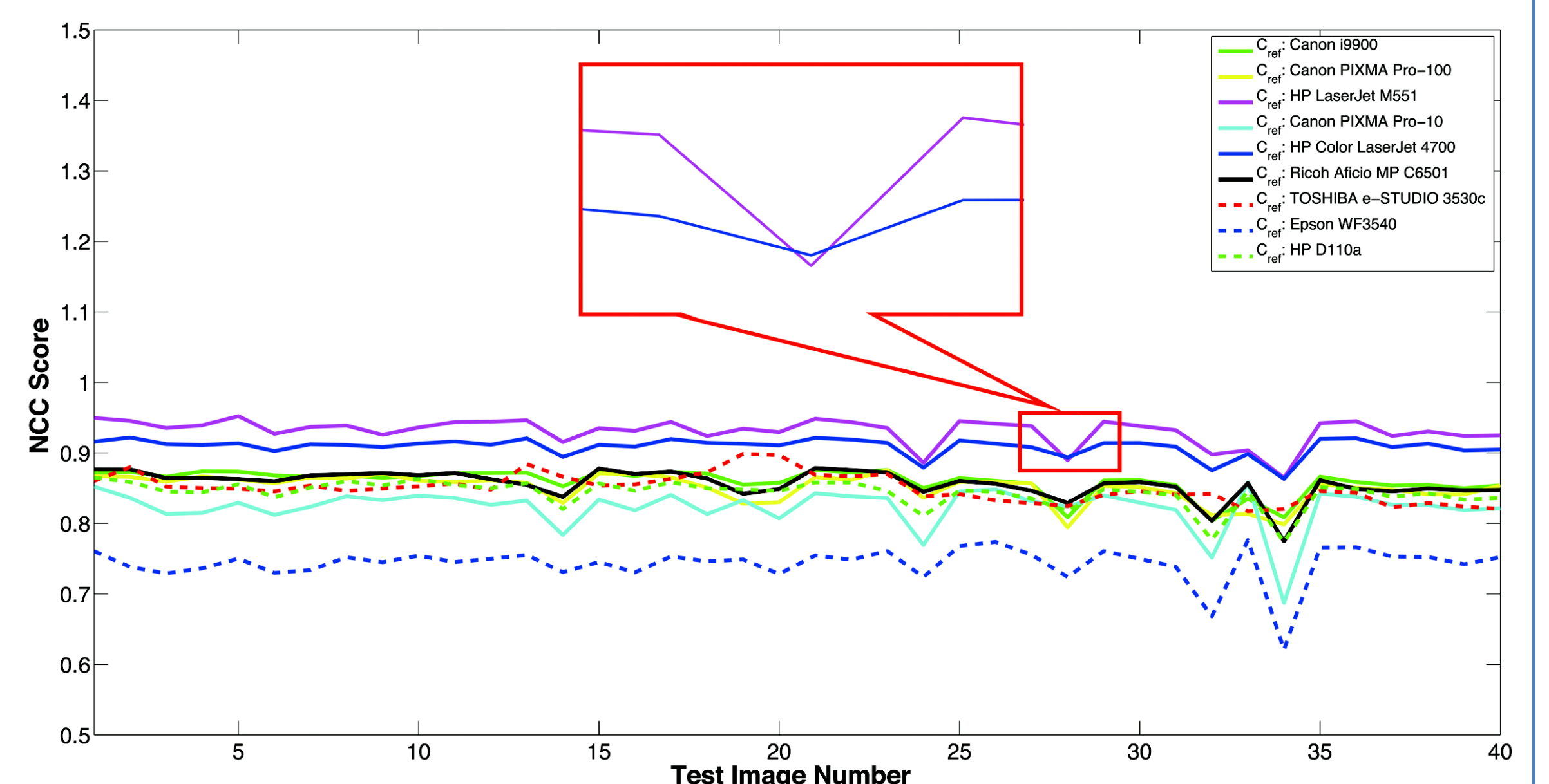
- A binary sequence is obtained from the binarized marks.
- Error control using binarized marks will only be used under conditions where we can not confidently estimate the printer index based on the NCC score.

Experimental Results

- We test our NCC-based method for FMs printed using 9 different printers.
- 579 test images were obtained under various lighting conditions.
- The accuracy of estimated printer index based on average NCC scores from 9 printers (note that printer printers with “*” are laser printers) are:

Testing Printer	A	B	C*	D	E*	F*	G*	H	I
A	0.968	0.944	0.846	0.815	0.941	0.948	0.897	0.794	0.92
B	-0.863	0.965	0.785	0.786	0.835	0.882	0.794	0.719	0.809
C*	-0.86	0.851	0.931	0.823	0.909	0.856	0.85	0.743	0.843
D	-0.784	0.8	0.803	0.957	0.819	0.81	0.725	0.821	0.754
E*	-0.906	0.869	0.832	0.769	0.959	0.874	0.873	0.797	0.862
F*	-0.893	0.878	0.762	0.743	0.879	0.95	0.826	0.739	0.847
G*	-0.883	0.829	0.796	0.719	0.911	0.849	0.953	0.754	0.865
H	-0.809	0.746	0.668	0.804	0.818	0.777	0.745	0.954	0.797
I	-0.902	0.867	0.777	0.749	0.889	0.867	0.861	0.79	0.967

- A subset of 40 images from our set of test images were used for testing the error control. The two lines inside the red rectangular area show an example of an incorrect printer being selected based on NCC alone. It was corrected by the error control method.



Conclusion and Acknowledgement

- We have demonstrated printer indexing can be used for our FMs.
- This work was sponsored by grant from the National Institutes of Health under grant NIEH/NIH 2R01ES012459-06.