An Interaction Design Framework for Adaptive Lighting Systems

Cesar Armando Torres[1], Matthew Aldrich[2], Joseph Paradiso, Ph.D.[2]

[1]Department of Art, Department of Computer Science, Stanford University, Stanford CA
[2]Responsive Environments Group, MIT Media Lab, Massachusetts Institute of Technology,Cambridge, MA

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Human Factors

Usability Survey

Optimal lighting levels are *higher*
More than 70% choose below optimal lighting levels for task and reading performance.[1,2]

Perceived interaction is high, actual interaction is low
Interaction occurs typically less than once every month.[1]

Reverting to the old ways
If the user does not understand the system, they revert to conventional system control.

Presets are not used
Users do not know how to set them or what each one does. We leave the lights on in anticipation of returning to a work area. Switching only occurs during arrival and departure from work.

Only *one* visual language
Since light is intangible, it suffers from no natural mapping and must thus rely on past interfaces such as switches, dimmers, presets.

Control is overrated?
The ability to control lights does not affect subject mood, alertness, or performance.[3] However, users carry more positive attitudes about adaptive lighting control and satisfaction with lighting levels.

Overview

Minimal interaction occurs with adaptive lighting controls which can lead to unhealthy lighting conditions and reduced task performance. We developed an interacton framework that uses:

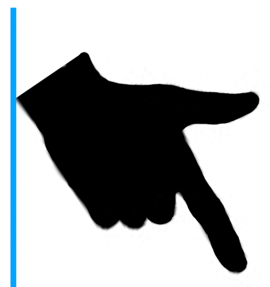
Object Oriented Design

In order to facilitate rapid prototyping, we implemented an object-oriented framework that is centered on optically trackable objects. Post-its, with unique color, affordances, and economability, were used to facilitate interactions. Each object would monitor its own properties (hand events, position, etc...) with a similar approach to GUI development.

Color Tracking

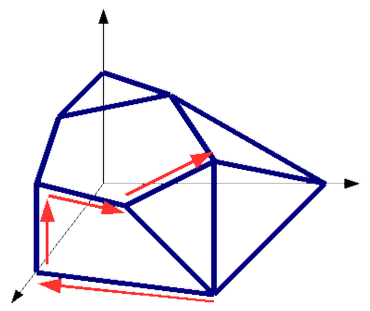
Lighting invariant tracking can be achieved using a probabilistic color segmentation method known as HS back projection and is popular for skin identification. We normalize hue ranges under low lighting conditions for functionality down to as little as 3 lux.

Gesture Recognition



Using a skin-based back projection, we were able to identify and extract hand feature vectors using connected component analysis, best-fit ellipse, and camshift tracking. With two-dimensional orientation histograms, we trained a classifier to identify four hand gestures.

Simplex Linear Programming



The simplex algorithm defines a polytype constrained by a set of linear inequalities.
In the case of adaptive lighting, we minimize on energy output and are constrained by the maximum output of light fixtures and the user-defined illuminance level. It moves along its edges until it finds the vertex of the optimal solution.

which allows for adaptive lighting systems to use the relationship between humans and objects to create rich sensory experiences and improve usability.

Prototype

Dark and light adaptation

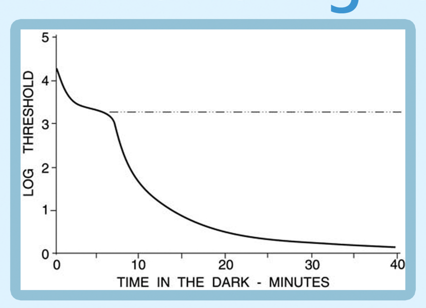


Figure 1: Dark adaptatation curve. Dashed line defines mesopic vs. photopic conditions.
E.B Goldstein. *Sensation and perception*. Wadsorth Cengage Learning, 2009.

Uses a special time constraint to ensure that the system does not exceed the physiological capabilities of the eye in adjusting to dramatic changes in lighting conditions. Mesopic conditions required at least 30 minutes for adaptation while photopic recovery was as quick as a minute.

Transferrable Control

Uses the natural relationship between objects and users. The interface becomes the object allowing for natural behavior to control system functionality.

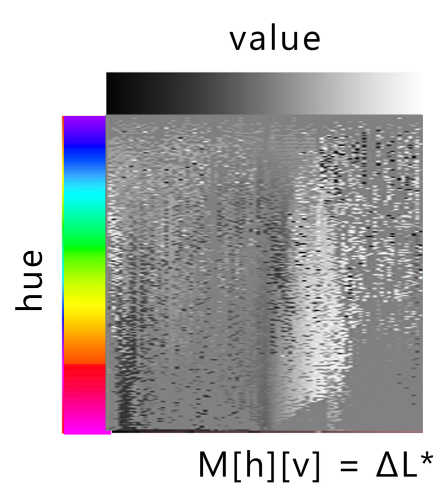
Multimodal Cues

Maps MIDI sound cues to visual cues in order to lessen cognitive loads. Lower pitches were mapped to higher and lower brightness values to encourage higher user settings.

Natural Mapping

Post-it actors are defined to control a specific light structure and naturally map based on the geophysical arrangement of the system.

Evaluation



Our brightness extraction model was able to effectively transform reflected light to account for the "black box" problem for sampled regions that correlated with sampled calibrated color. We observed 10% to 20% error in whitepoint luminance values .

The figure on the left shows the change in L* based on the HL pixel values. Each pixel designates a possible H and L combination. Notably blue hues show the largest gaps in sampling behavior which can also help explain observed tracking properties on the right.

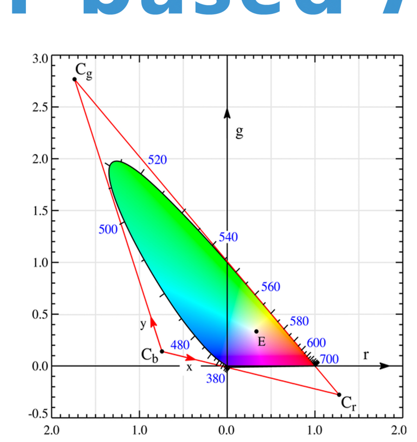
Color tracking

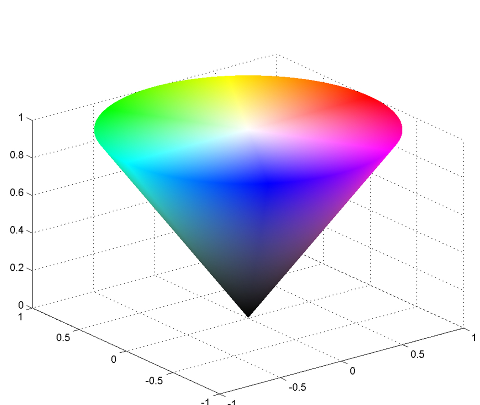
Color	Hue	Minimum lux
Orange	120	8
Pink	130	22
Yellow	110	37
Green	70	37
Turquoise	20	59
Blue	0	150

Future Works

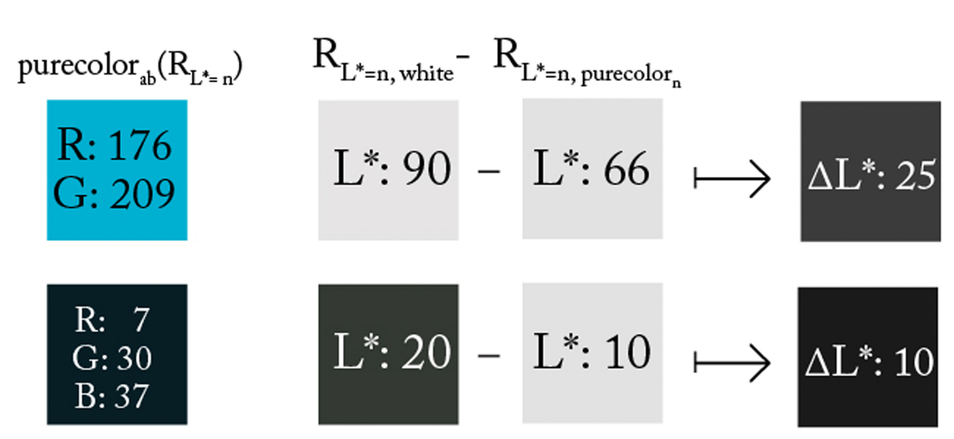
We plan to enact a series of usability tests to rigorously test transferrable control in interaction design. We are also interested in the use of the YCrCb space as a stronger indicator of chromaticity and luminance extraction. In our work, we encountered a potential means of surface classification by noting incongruencies from our brightness extractions models. We also plan to implement further control structures such as three dimensional space *point-and-control* gesture recognition.

Vision-based ALS Design





CIE L*a*b* and HSV ⟶



Luminance extraction ⟶

Simulataneous brightness

Works Referenced

T Moore, DJ Carter, and AI Slater. Long term patterns of use of occupant controlled office lighting. *Lighting Research and Technology*, 35(1) 43-57, 2003.
AR Bowers, C Meek, N Stewart. Illumination and reading performance in age-related macular degeneration. *Clinical and Experimental Optometry*, 84(3): 139-147, 2001.
P. R. Boyce, H. Eklund, and S. N. Simpson. Individual lighting control : Task performance, mood, and illuminance. *Journal of Illuminating Engineering Society*, 131-142, 2000.

Acknowledgements

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