

AIA Certified Vision Professional
Advanced Color Machine Vision and Applications
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Presentation Notes, References and Attributions

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Introduction

Welcome

The **bold purple** color, that indicates important terms, should be a visible color to all three types of color blind individuals. The Red, Green, Blue (RGB) values are 102, 0, 255 and should appear as blues or green to color blind individuals.

See <http://safecolours.rigdenage.com/>

What is Color?

Isaac Newton's *Opticks*, editions from 1704 to 1730: "...to speak properly, the rays are not coloured..." Color is not a "property" of electromagnetic radiation (light) but is a function of our brain's processing of light. <http://en.wikipedia.org/wiki/Opticks>
More on the philosophical issue: <http://colourware.wordpress.com/2009/06/30/the-rays-are-not-coloured/> Spectrum: <http://www.chm.davidson.edu/vce/coordchem/color.html>
Spectral range of human vision: <http://www.yorku.ca/eye/spectrum.gif>

Important Uses of Color Vision – *List of items covered next*

Material Property

Image of Wood and Copper monkey head:

http://en.wikibooks.org/wiki/Blender_3D:_Noob_to_Pro/Every_Material_Known_to_Man/Copper

Papers about "Material Property":

<http://www.journals.elsevier.com/vision-research/call-for-papers/special-issue-on-perception-of-material-properties/>

<http://www.journalofvision.org/content/4/9.toc>

Which Cherries are Ripe?

Color vision makes it easy to find the rip (red) and unripe (yellow – orange) cherries.

Cherry image from: <http://www.msue.msu.edu/fruit/tchrygrw.htm>

This demonstrates color afterimages. Hold your eyes fixed while flipping between the color and monochrome images. Red and orange cherries will briefly appear to be greenish in the monochrome image. The effect disappears when you move your

eyes. Color afterimages are one of the many reasons why the human eye is not a good measurement tool – a gauge shouldn't give different readings depending on its history.

Afterimages demonstrate adaptation, the adjustment of the human visual system to colors, so that so that color changes (important!) are easier to perceive.

Color Inspection and Sorting

Peanuts image from: http://sst-web.tees.ac.uk/external/u0003076/food_hygiene/spoilage/WebFoodspoilage.htm

Currency image from: http://www.hrharmer.com/auctions/Legacy/2985-2/2985-2_09.html Currency inspection is a very difficult task for people.

Searching and Locating

Sneaker image from: <http://theshoegame.com/articles/sneaker-eye-candy-volume-5.html>

Finding the light, blue sneakers is fast and easy (even for most color blind viewers). Our brain seems to do this search “in parallel” and with no conscious effort.

Now try to find all the sneakers with the Nike “Swoosh” and you will have to carefully look at every part of the image. This “serial search” is a lot harder.

Importance of Fast Color Search

We can quickly detect a poisonous snake by its color.

Milk snake image from: <http://en.wikipedia.org/wiki/Snake> (a Batesian mimic of the poisonous coral snake http://en.wikipedia.org/wiki/Batesian_mimicry)

Fruit image from: http://en.wikipedia.org/wiki/Fruit_tree

Measuring and Matching

Color matching image: <http://www.konicaminolta.com/instruments/products/color-measurement/spectrophotometer/cm2600d-2500d/index.html>

pH Test strip image from:

<http://www.ph-ion.com/index.asp?PageAction=VIEWCATS&Category=205>

Color Coding

Color encoding for 3D from:

http://www.siemens.com/press/en/pp_ct/2007/soct200701_03_%28_in_auto%29_1427844.htm

SMT pseudo color: http://www.smtonline.com/pages/zone.cgi?a=60050&_pf_=1

Color coded ants: <http://blogs.scientificamerican.com/observations/2012/02/17/color-coding-ants/>

“Rainbow wire” image: <http://letsmakerobots.com/files/userpics/u1533/rainbowwire.jpg>

Bar Coding

MobiTags™: <http://tag.microsoft.com/what-is-tag/2d-barcodes.aspx>

Rail Barcode: <http://www.flickr.com/photos/andrew-turnbull/6088353227/>

See for discussion: <http://roustaboutextra.wordpress.com/>
http://commons.wikimedia.org/wiki/File:High_Capacity_Color_Barcode.png

Human Color Vision – *items covered next*

Individual Differences

Color blindness test from: http://en.wikipedia.org/wiki/Color_perception_test

Low Resolution Color

Shows NTSC “chroma crawl” or “dot crawl” http://en.wikipedia.org/wiki/Dot_crawl

Influenced by Surroundings

Lotto Cube illusion: <http://www.moillusions.com/2008/02/color-tile-illusion-new-aspect.html> or
http://scienceblogs.com/startswithabang/2010/02/weekend_diversion_a_question_o.php

The orange square in the center of the shadowed face of the colored cube is exactly the same color as the brown square on the top of the cube and the square on the checkerboard surface.

Other illusions: <http://www.psy.ritsumei.ac.jp/~akitaoka/color12e.html>

Color Machine Vision (two slides)

Image of color printing inspection system: http://www.eyec.de/index_eng.html

Image of pharmaceutical inspection system: <http://www.teledynedalsa.com>

Image of skin mole: <http://skincancer.about.com/od/symptoms/ss/mole.htm>

Some Markets for Color MV

Reference: <http://www.machinevisiononline.org/market-data.cfm>

Physics of Color Imaging

Light

Sunlight image from: <http://en.wikipedia.org/wiki/Light>

Photons http://wisp.physics.wisc.edu/astro104/lecture7/lec7_print.html

Wavelength or Frequency

Energy and Intensity

<http://www.pveducation.org/pvcdrom/properties-of-sunlight/energy-of-photon>

An electron volt is the energy required to raise an electron through 1 volt.

$$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$$

Flux = # photons / (sec meter²) as a function of wavelength. (photon energy) * flux as a function of wavelength gives “spectral power density” or radiant flux, a measure of energy / time*area

Radiometric vs. Photometric

Power is energy / time, so watts = joules / second

Radiometric for physical measures and photometric for human perceptual measures

<http://en.wikipedia.org/wiki/Radiometry>

http://en.wikipedia.org/wiki/Photometry_%28optics%29

Spectrum (Radiometric)

<http://en.wikipedia.org/wiki/Sunlight>

Polarization

http://en.wikipedia.org/wiki/Polarized_3D_system

http://en.wikipedia.org/wiki/Haidinger%27s_brush

Spatial Configuration

Image of color changing ink on \$100 bill:

<http://www.pbs.org/wgbh/nova/military/anatomy-bill.html>

Ratios of Color Sensor Types

Cone response graph from <http://homepages.cwi.nl/~steven/Talks/2012/01-13-steven-colour/>

Metamers

Rough graphics by B.D.

Model of Color Image Formation

Spectral Reflectance Curve from https://www.sabic-ip.com/staticcxp/user/en/LearnAboutColor/ColorBasicsDetail/reflectance_curves.html

A Mathematical Model

This model approximates color image (sensor output) formation. There are many variations of this kind of model. The important points are that the sensor outputs are a integrated product (an inner product in vector terms) of the illumination spectrum, the object reflectance or transmission, and the sensor responses; and, the “imaging geometry” (my term for the position and angles of lights, objects, and sensors; and the sensor acceptance angle. We need to know or control these factors to recover object color from sensor outputs.

Diagram of Imaging Model

The model is for the physical aspects of color image formation, but the computational factors (Processing) are also important in human perception and, obviously, in machine vision.

The Color Vision Problem

Given the sensor outputs, recover the illumination and then recover the object’s spectrum.

Recovering the Illuminant

Light “tent” image: Teledyne DALSA

Vision is Under-constrained

A single image doesn’t contain enough information to reliably recover color.

<http://www.codeproject.com/Articles/15935/Yet-Another-RayTracer-for-NET>

Illumination *Introductory Graphic*

Black Body Radiators

http://en.wikipedia.org/wiki/Black_body

<http://casa.colorado.edu/~ajsh/colour/Tspectrum.html>

Black Body Radiation

<http://www.as.utexas.edu/~sj/a301-fa06/>

Color Temperature

<http://www.mediacollege.com/lighting/colour/colour-temperature.html>

Correlated Color Temperature

<http://en.wikipedia.org/wiki/File:Incand-3500-5500-color-temp-comparison.png>

Objects

Leaf reflection image: <http://zebu.uoregon.edu/2000/ph102/lec19.html>

Reflectance and Transmission

Top: [https://www.sabic-](https://www.sabic-ip.com/staticcxp/user/en/LearnAboutColor/ColorBasicsDetail/reflectance_curves.html)

[ip.com/staticcxp/user/en/LearnAboutColor/ColorBasicsDetail/reflectance_curves.html](https://www.sabic-ip.com/staticcxp/user/en/LearnAboutColor/ColorBasicsDetail/reflectance_curves.html)

Bottom: <http://www.fli-cam.com/images/Product%20Images/fli%20filters.jpg>

Additive Color

<http://chipl.edublogs.org/2010/11/25/isaac-newton/>

http://en.wikipedia.org/wiki/Color_space

Subtractive Color

http://en.wikipedia.org/wiki/Color_space

Example: LEDs and LCDs

Left: stock

Right: <http://express.howstuffworks.com/exp-tv3.htm>

Color Filters

Transmission filters: <http://www.creativeapplications.net/sound/tangible-color-music-instrument-openframeworks-sound/>

Surface Plasmon color generation:

<http://www.timkelf.com/researchsurfaceplasmons.html>

Lycurgus cup – an interesting example of surface plasmon color generation:

<http://nanoden.blogspot.com/2010/12/plasmonics-at-bottom-shrinking.html>

Depicts King Lycurgus (Lye-KUR-gus) of Thrace being dragged to the underworld. Reflects blue-green, transmits red. So when lit from outside appears blue-green and when lit from inside appears red.

Color filtering can also be produced by scattering

<http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/blusky.html>

Material Reflectance

Reflection maps from <http://www.flickr.com/photos/mitopencourseware/4815499473/>

Diffuse Reflectance

Lambertian Reflectance is the ideal, but not often met by real diffuse surfaces

http://en.wikipedia.org/wiki/Lambertian_reflectance

http://www.its.bldrdoc.gov/fs-1037/dir-020/_2967.htm

Specular Reflection

Image: http://cct.rncan.gc.ca/glossary/index_e.php?id=3133

Discussion: <http://commons.wikimedia.org/wiki/File:Specular-Reflection-1.png>

Pigmented Reflection

<http://www.ijvs.com/volume1/edition5/section1.html>

http://en.wikipedia.org/wiki/Fresnel_equations

Interference Colors

Image: http://commons.wikimedia.org/wiki/Category:Interference_color

(<http://commons.wikimedia.org/wiki/File:Oelfleckerp.jpg>)

Image: Daniel Klarmann, <http://mrtitanium.com/images/wave-interference.gif>

Reference: <http://en.wikipedia.org/wiki/Iridescence>

Color Shifts with Geometry

Butterfly image from: <http://www.photonics.com/Article.aspx?AID=27660>

Bubbles image from: <http://en.wikipedia.org/wiki/Iridescence>

Combination of Reflectance Types

<http://www.glenspectra.co.uk/glen/spectroradiometry/images/reflectivity.gif>

For highly detailed reflection mapping, use BRDF

http://en.wikipedia.org/wiki/Bidirectional_reflectance_distribution_function

http://cct.rncan.gc.ca/glossary/index_e.php?id=212

Sensors – introductory graphic

Color Vision Sensors

Zebrafish retina: http://www.biology.ualberta.ca/faculty/ted_allison/

Bayer pattern:

http://www.cfar.umd.edu/~jneumann/videogeometry/CMSC828Z/project1/RGB_Bayer.htm

Human Eye

Image: <http://www.ecse.rpi.edu/~schubert/Light-Emitting-Diodes-dot-org/chap16/F16-01%20Human%20eye.jpg>

Reference: http://en.wikipedia.org/wiki/Scotopic_vision

Retina and Fovea

<http://www.blueconemonochromacy.org/what-is-bcm/eye-retina-and-cones-2/>

<http://hyperphysics.phy-astr.gsu.edu/hbase/vision/rodcone.html>

http://www.phys.ufl.edu/~avery/course/3400/gallery/gallery_vision.html

Human Cone Sensor Types

<http://en.wikipedia.org/wiki/Photopsin>

<http://www.handprint.com/HP/WCL/color1.html> (Copyright ©, Bruce McEvoy)

Cone Distribution

Packing arrangement of the three cone classes in primate retina, by Austin Roorda, Andrew B. Metha, Peter Lennie, David R. Williams. Vision Research 41 (2001) 1291–1306.

Camera Color Sensors

Sensor “chip” drawing: <http://digital.pho.to/>

http://www.daviddarling.info/encyclopedia/P/plano-convex_lens.html

http://www.astronomics.com/celestron-nightscape-ccd-camera_p19460.aspx

Camera Sensors’ Responses

Camera image and response curves: Teledyne DALSA

Human spectral response curves: <http://www.handprint.com/HP/WCL/color1.html>

DN =

<http://www.pixelink.com/umbraco/supportkb/?solution=/ui/selfservice/pkb/PublicKnowledgeSolution/d?&id=5018000000SDjaCsY>

Human Color Vision

<http://www.futurity.org/tag/psychology/page/13/>

www.merringtons.com.au

Pop Quiz!

An attempt to induce “active learning”

As the Sun Goes Down...?

http://en.wikipedia.org/wiki/Photometry_%28optics%29

A “thought experiment” on the Purkinje Shift

http://en.wikipedia.org/wiki/Purkinje_effect

Retinal Processing

<http://webvision.med.utah.edu/GCPHYS1.HTM>

Retinal Processing of Colors

Drawing by BD

http://en.wikipedia.org/wiki/HSL_and_HSV

<http://www.yorku.ca/eye/toc-sub.htm>

Color Opponency Demo

How's Your Hering?

Color afterimages demonstrate R-G and B-Y opponency

Perceptual Color Terms

These are terms used to describe human perception of color

<http://en.wikipedia.org/wiki/Colorfulness>

Human Color Sensitivity

Light Science: Physics and the Visual Arts By Thomas D. Rossing, Christopher J. Chiaverina

<http://www.hiddenvalleynaturearts.com/images/blushingpeach.jpg>

<http://www.polyvore.com/cgi/img-thing?.out=jpg&size=l&tid=52189530>

<http://www.visualexpert.com/FAQ/Part2/cfaqPart2.html>

Some Retinal Processing

Retinal and Cortical Processing

Color Processing Paths

http://en.wikipedia.org/wiki/Color_vision

<http://www.dana.org/news/cerebrum/detail.aspx?id=1222>

http://en.wikipedia.org/wiki/Visual_cortex

http://www.merck.com/media/mmhe2/figures/MMHE_20_224_02_eps.gif

Psychophysics

<http://www.bccn-tuebingen.de/research/cluster-a/a2.html>

A study of retinal function with image defocus

<http://www2.le.ac.uk/departments/psychology/research/language-and-vision/vision-and-language-group-photo-gallery>

Measuring Human Color Vision

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/miller-royer_color_portland2013.pdf

Dependence on Field of View

http://en.wikipedia.org/wiki/Visual_angle

<http://www.perceptionweb.com/abstract.cgi?id=p200415>

CIE Color Matching Functions

<http://sensing.konicaminolta.asia/learning-center/color-measurement/general-color-terms/>

http://en.wikipedia.org/wiki/CIE_1931_color_space

CIE Color Matching Functions (*second slide*)

http://en.wikipedia.org/wiki/CIE_1931_color_space

Measuring XYZs

<http://www.pcimag.com/articles/understanding-color-communication>

http://www.xrite.com/documents/literature/en/L10-001_Understand_Color_en.pdf

Color Space

Left: <http://7art-screensavers.com/screenshots/fruits/>

Right: Teledyne DALSA

Color Mixing http://en.wikipedia.org/wiki/Color_space

CIE XYZ Color Space

<http://www.couleur.org/?page=transformations>

CIE xyY Color Space

<http://www.handprint.com/HP/WCL/color6.html>

<http://www.cs.kent.edu/~farrell/cg02/lectures/color/colour.html>

<http://www.couleur.org/?page=transformations>

Projection onto xy

<http://cdn.intechopen.com/pdfs-wm/38362.pdf>

<http://sensing.konicaminolta.asia/learning-center/color-measurement/color-spaces/>

CIE Chromaticity Diagram

<http://www.pcimag.com/articles/understanding-color-communication>

Gamut

<http://www.allquests.com/question/3710060/Sonys-XBrite-FullHD-vs-Dells-RGBLED-for-photo-editing.html>

See also NTSC gamut: <http://www.behardware.com/articles/570-1/lumileds-the-future-of-the-lcd.html>

Non-Spectral Colors

<http://www.yorku.ca/eye/nonspect.htm>

Why is CIE Color Important?

Planckian Locus: <http://en.wikipedia.org/wiki/File:PlanckianLocus.png> and

http://wapedia.mobi/en/Planckian_locus

Paint samples: http://www.normankoren.com/CIE_xy_Spaulding_realworld.jpg

Example: $L^*a^*b^*$

<http://www.techbriefs.com/component/content/article/10-ntb/tech-briefs/bio-medical/13285>

http://www.xrite.com/documents/literature/en/L10-001_Understand_Color_en.pdf

<http://www.couleur.org/?page=transformations>

Another View of CIE $L^*a^*b^*$ Axes

http://www.xrite.com/documents/literature/en/L10-001_Understand_Color_en.pdf
<http://www.flexoglobal.com/flexomag/08-September/flexomag-ploumidis.htm>

Calibrating MV to CIE

Why MV systems are difficult to calibrate to CIE XYZ color spaces

Tristimulus Colorimeter

<http://elektrophysikusa.com/>
http://img.directindustry.com/images_di/photo-g/portable-reflectance-colorimeter-322066.jpg

Inspecting Baked Goods

www.montrose-tech.com

English Muffin “Toast Mark”

Images © 2014, Ben Dawson

Muffin Inspection Details

Perceptually Uniform Color Spaces

http://en.wikipedia.org/wiki/MacAdam_ellipse

Making xy Perceptually Uniform

Non-Linear, Perceptually Uniform

<http://www.couleur.org/?page=transformations>

Munsell Color Space

Http://www.brucelindbloom.com/Eqn_RGB_XYZ_Matrix.html
<http://www.russellcottrell.com/photo/matrixCalculator.htm>
<http://code.google.com/p/cuda-convnet/wiki/LayerParams>
<http://www.codeproject.com/KB/directx/d3dmunsell.aspx?msg=881279>

Converting from MV's RGB

Example: YUV (linear from RGB)

<http://www.couleur.org/?page=transformations>
<http://en.wikipedia.org/wiki/YUV>

More on Individual Differences

http://en.wikipedia.org/wiki/Color_blindness
<http://faculty.washington.edu/chudler/gif/colf7.jpg> Color blindness test images
<http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/V/Vision.html>

Packing arrangement of the three cone classes in primate retina, by Austin Roorda, Andrew B. Metha, Peter Lennie, David R. Williams. Vision Research 41 (2001) 1291–1306.

Color Fills Luma Edges

Spatial Frequency

Color Constancy

http://en.wikipedia.org/wiki/Color_constancy

<http://www-psych.stanford.edu/~lera/psych115s/notes/lecture5/>

Adaptation

<http://www.psy.ritsumei.ac.jp/~akitaoka/shikisai2005.html>

http://en.wikipedia.org/wiki/Same_color_illusion

http://en.wikipedia.org/wiki/File:Optical_grey_squares_orange_brown.svg

Adaptation Example

<http://haroldrossfineart.wordpress.com/2011/06/24/visual-adaptation-our-friend-and-our-enemy/>

McCollough Effect

http://en.wikipedia.org/wiki/McCollough_effect

Mom Quiz!

Let's Choose a Paint Color...

<http://lebaroninteriors.blogspot.com/2011/04/designer-tip-tuesday-choosing-paint.html>

Towards Painting Harmony

McCollough Effect Test

http://en.wikipedia.org/wiki/McCollough_effect

Color Machine Vision Systems

Title slide by Ben Dawson

Color Measurement Tools

[http://en.wikipedia.org/wiki/Colorimeter_\(chemistry\)](http://en.wikipedia.org/wiki/Colorimeter_(chemistry))

<http://en.wikipedia.org/wiki/Spectrograph>

http://en.wikipedia.org/wiki/CIE_1931_color_space

Colorimeter: http://img.directindustry.com/images_di/photo-g/portable-reflectance-colorimeter-322066.jpg

Spectrometer: <http://www.prophotowiki.com/w/index.php/Spectrophotometer>

Spectrometer and Hyperspectral

http://www-cger.nies.go.jp/cger-j/db/enterprise/remote/images/db05_fig6.jpg

Color Sensors

Keyence <http://www.keyence.com/products/sensors/rgb/czv20/czv20.php>

Color Machine Vision Systems

Overview of features and components

CMVS Example: Gelcap Inspection

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Part Presentation & Environment

Image: http://www.odenberg.com/images/titan_sorter.gif

Reference: http://www.odenberg.com/sorting_packers.htm

Desired Illumination for CMV

http://scienceblogs.com/startswithabang/2009/07/why_do_stars_twinkle.php

Why (not) use Incandescent

<http://zeiss-campus.magnet.fsu.edu/articles/lightsources/tungstenhalogen.html>

http://www.moonbattery.com/archives/2007/03/light_bulbs_tar.html

Fluorescent Lights

http://www.gelighting.com/na/business_lighting/education_resources/learn_about_light/distribution_curves.htm

RGB “White” LEDs

http://www1.jands.com.au/support/product_support/lighting_technical_materials/what_to_look_for_when_judging_an_led_fixture146s_colour_mixing_capabilities133

White Phosphor LEDs

http://www.photonstartechnology.com/learn/how_leds_produce_white_light

<http://www.mvlg.info/images/photos/led/spectral3.jpg>

LEDs in Chromaticity Diagram

<http://www.olympusmicro.com/primer/lightandcolor/ledsintro.html>

http://cdn.cbsi.com.au/story_media/339301439/samsung-syncmaster-xl2370-cie-before2.jpg

Why (not) LEDs?

<http://www.olympusmicro.com/primer/lightandcolor/ledsintro.html>

LED Color Changes with Current

<http://www.lrc.rpi.edu/programs/solidstate/pdf/dyble-SPIE2005.pdf>

Some White LED Lights

Advanced Illumination, Inc. <http://www.advill.com/>

Filters

Midwest Optical <http://www.machinevisionfilters.com/>

Why Filter a Color Image!?

Teledyne DALSA, Inc.

<https://www.bintelshop.com.au/HTML/0500Filter.jpg>

Monochrome “Color Imaging”

Midwest Optical Systems, Inc.: <http://www.machinevisionfilters.com/>

“Correcting” Some Color Blindness

<http://enchroma.com/>

http://pogue.blogs.nytimes.com/2013/08/15/glasses-that-solve-colorblindness-for-a-big-price-tag/?_php=true&_type=blogs&_r=0

Here is a cure if you are up for gene therapy...

<http://news.sciencemag.org/sciencenow/2009/09/16-01.html>

Lenses for CMVS

<http://www.schneideroptics.com/>

Lens Chromatic Aberration

[http://en.wikipedia.org/wiki/Lens_\(optics\)](http://en.wikipedia.org/wiki/Lens_(optics))

<http://www.yorku.ca/eye>

http://commons.wikimedia.org/wiki/File:Chromatic_aberration_convex.svg

Color Cameras

Teledyne DALSA www.TeledyneDalsa.com

Bayer Pattern Sensors

Teledyne DALSA www.TeledyneDalsa.com

Bayer Pattern “Removal”

<http://media.photobucket.com/image/bayer%20interpolation/industry7/Bayer.png>

Bayer Pattern Color Noise

Teledyne DALSA www.TeledyneDalsa.com

Spatial Frequency Response

<http://www.owl.net/rice.edu/%7Epsyc351/Images/ModulationTransferFunction.bmp> and

<http://en.wikipedia.org/wiki/File:SinVibr.png>

<http://www.microsoft.com/appliedsciences/content/projects/ClearTypeDisplay.aspx>

Digital Sampling & Aliasing

<http://support.svi.nl/wikiimg/Aliasing-plot.png>

Color Aliasing

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Color vs. Resolution

3 CCD Cameras (1)

www.jai.com/en

3 CCD Cameras (2)

www.jai.com/en

Color Line Scan Cameras

Teledyne DALSA www.TeledyneDalsa.com

Living with the Bayer

<http://buddy2blogger.blogspot.com/2012/01/edge-of-edden-living-with-grizzlies.html>

In-Camera Processing

Teledyne DALSA www.TeledyneDalsa.com

Gain and Offset, A to D

Color Space Conversions, LUTs

The Curse of Gamma

http://www-graphics.stanford.edu/images/skitrip95_fixed.jpg

Gamma Off

http://www-graphics.stanford.edu/images/skitrip95_fixed-gamma17.jpg

Gamma On

<http://www-graphics.stanford.edu/gamma.html>

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Gamma Curves

Color MV Processors (*introduction slide*)

Color “Smart Cameras”

Teledyne DALSA www.TeledyneDalsa.com

PC-Based Processors

Teledyne DALSA www.TeledyneDalsa.com

Attached Processor

Teledyne DALSA www.TeledyneDalsa.com

Tips (1)

Basic Color MV Algorithms

Camera Setup

Three terms, often confused. Standard vs. Comparative calibration.

White Balance Example

<http://upload.wikimedia.org/wikipedia/commons/0/01/Lily-M7292-As-shot-and-manual.jpg>

<http://www.cambridgeincolour.com/tutorials/white-balance.htm>

Color Balance for Human Viewing

www.xrite.com

http://marsrover.nasa.gov/mission/spacecraft_instru_calibr.html

Comparative Calibration

All need to Recover the Illuminant

<http://blog.xritephoto.com/2009/12/getting-white-balance-right/>

Color Constancy (again)

<http://www.colorcube.com/illusions/chrmadptb.htm>

http://en.wikipedia.org/wiki/Color_constancy

White Balance Methods

Violating Gray World Assumption

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Color Balance

www.TeledyneDalsa.com and www.xrite.com

Color Balance Methods

Color Balance Example

Retinex Algorithms

http://en.wikipedia.org/wiki/Color_constancy

Best Use a Reference Patch

www.ceram.com

Reference Patch Example

Teledyne DALSA www.TeledyneDalsa.com

Color Space Conversions

http://www.personal.psu.edu/cab38/GEOG321/04_color02/Munsell3D.gif

Linear, 3 Color

<http://msdn.microsoft.com/en-us/library/aa511283.aspx>
http://software.intel.com/sites/products/documentation/hpc/ipp/ippi/ippi_ch6/ch6_color_models.html

Example: YIQ (linear)

<http://www.couleur.org/index.php?page=transformations>

Non-Linear, Perceptually Uniform

<http://www.blackice.com/colospaceHSI.htm>
<http://casa.colorado.edu/~ajsh/colour/rainbow.html>
<http://www.couleur.org/index.php?page=transformation>

Color Space Conversion Issues

Example: Gelcaps

Teledyne DALSA www.TeledyneDalsa.com

Remove Luminance

Teledyne DALSA www.TeledyneDalsa.com

Tips (2)

Computing Application Answers

<http://www.dementiatoday.com/brain-fibers-in-living-color-may-help-predict-the-spread-of-dementia/>

Color Statistics

<http://www.picture-newsletter.com/vegetables/>

Joint Statistics

Color Spot Meter

Example: Mouthwash

Teledyne DALSA www.TeledyneDalsa.com

More Mouthwash

Teledyne DALSA www.TeledyneDalsa.com

Color Classifiers

<http://www.ahinson.com/res3.htm>

Threshold Classifiers

Threshold Classifier Example

Cherries image: <http://www.msue.msu.edu/fruit/tchrygrw.htm>

Threshold CAFs' Poor Performance

<http://www.picture-newsletter.com/vegetables/>

Part Location by Color

Teledyne DALSA www.TeledyneDalsa.com

Gaussian CAFs

Automated Weeding

<http://ucce.ucdavis.edu/files/repositoryfiles/ca5804p218-69159.pdf>

Automated Weeding System

<http://ucce.ucdavis.edu/files/repositoryfiles/ca5804p218-69159.pdf>

Radial Basis CAFs

<http://www.roselladb.com/predictive-modeling.htm>

<http://www.pptsworld.com/2012/02/radial-basis-function-in-neural-network.html>

Support Vector Machines

http://moonflare.com/blogfiles/devdev/Rosa_Gold_Glow_2_small_noblue_color_space.png

http://en.wikibooks.org/wiki/Data_Mining_Algorithms_In_R/Classification/SVM

Class Probability

Misclassification

Training a Classifier

Training a Color Classifier

Teledyne DALSA www.TeledyneDalsa.com

Thresholds and Error Costs

Cost Functions

Example: Grading Seed Corn

Teledyne DALSA www.TeledyneDalsa.com

Seed Corn Grading

Teledyne DALSA www.TeledyneDalsa.com

Breakfast Meal Check

Teledyne DALSA www.TeledyneDalsa.com

Assembly Checking

Teledyne DALSA www.TeledyneDalsa.com

Automotive Verification

Teledyne DALSA www.TeledyneDalsa.com

Assembly Verification

Teledyne DALSA www.TeledyneDalsa.com

Difficult Algorithms for Color

Bilateral Filtering

<http://users.soe.ucsc.edu/~manduchi/Papers/ICCV98.pdf>

Color Map from Classifier

Teledyne DALSA www.TeledyneDalsa.com

Color Defects and Dimensioning

Teledyne DALSA www.TeledyneDalsa.com

Plating Inspection – White Balance

Teledyne DALSA www.TeledyneDalsa.com

Plating Inspection – Find Defects

Teledyne DALSA www.TeledyneDalsa.com

Sorting Recycled Plastic

Teledyne DALSA www.TeledyneDalsa.com

Use a Color Map

Teledyne DALSA www.TeledyneDalsa.com

Color Map Blob Analysis

Teledyne DALSA www.TeledyneDalsa.com

Counting Bows

Teledyne DALSA www.TeledyneDalsa.com

Color Classify BACKGROUND

Teledyne DALSA www.TeledyneDalsa.com

Color Map to Show Only Bows

Teledyne DALSA www.TeledyneDalsa.com

Mars Rocks and Rovers Roll

<http://wpirover.com/>

Sample Rocks

<http://wpirover.com/>

HSV's Saturation Works Well

Clean up and "Blob Detect"

A Difficult Color Vision Problem

Additional References

The Joy of Visual Perception

<http://www.yorku.ca/eye>

Digital Color Imaging Handbook

[http://www.amazon.com/Digital-Handbook-](http://www.amazon.com/Digital-Handbook-Electrical-Engineering-Processing/dp/084930900X/ref=sip_rech_dp_6)

[Electrical-Engineering-Processing/dp/084930900X/ref=sip_rech_dp_6](http://www.amazon.com/Digital-Handbook-Electrical-Engineering-Processing/dp/084930900X/ref=sip_rech_dp_6)

General color references

<http://en.wikipedia.org/wiki/Color>

http://www.fz-juelich.de/inb/inb-1/Color_vision