メディア情報に関する不変量理論及び著作権保護への応用

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Riemann Geometry for Color Characterization and Mapping

Problem

The basic problem in color reproduction and color management is the construction of mapping between different devices and individual human observers

In color reproduction an ideal mapping should take into account subjective color differences

Today this requires in general the description of the mapping in the form of a look-up table

Solution

We use a general framework based on Riemann geometry for characterization of and mapping between color spaces

In the language of Riemann geometry color-difference preserving mappings are known as isometries. This framework provides algorithms to compute these isometries by solving differential equations.

Basic Riemann Geometry

Definitions: A Riemann space C with points x has a locally defined distance measure. It is defined by a positive definite matrix $G(x)$ on every point. In color applications spaces are 3D and at an infinitesimal distance near x the distance is is measured by

$$(dx, dx)_G = dx^T G(x) dx = g_{ij} dx^i dx^j$$

$$x = (x^1, \ldots, x^n)^T, G(x) = [g_{ij}]$$

The distance between two points x, x_0 in C is measured by the length of the geodesic, the shortest curve $x(t)$, between x and x_0.

$$l = \int_a^b \sqrt{g_{ij} \dot{x}^i \dot{x}^j}\, dt \qquad G = (g_{ij})$$

Points with fixed distance from a point x form an ellipsoid in the 3D euclidean space

The metric $G(x)$ can be estimated by:

measuring thresholds (just noticeable difference)

A map f from $\mathbf{R}^3 \rightarrow C$ with Jacobian matrix $D_f(x)$ defines

$$G(x) = D_f(x)^T D_f(x)$$

A local isometry is a map $f : C_1 \rightarrow C_2; y = f(x)$ between color spaces that preserves distances:

$$G_1(x) = D_f(x)^T G_2(y) D_f(x)$$

A map that preserves all jnd-thresholds preserves also large color differences

Uniformization, Color Spaces and Euclidean Spaces

An isometry u between a color space and a Euclidean space is called a uniformization map and the Euclidean space is colled an uniformization color space (UCS)

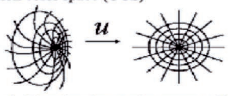

Figure 1. Mapping from color space to Euclidean space

A general map between color spaces C_1 and C_2 are constructed combining two uniformization maps u_1 and u_2

$$\begin{tikzcd} C_1 \arrow[rr, "f"] \arrow[dr, "u_1"'] & & C_2 \arrow[dl, "u_2"] \\ & U & \end{tikzcd} \qquad f = u_2^{-1} \circ u_1$$

Example: Color Reproduction

The metric $G(x)$ of the Riemann Geometry is computed from CIELUV based on the MacAdam ellipses

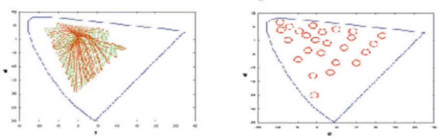

Figure 2. Riemann coordinates and Thresholds of CIELUV after uniformization

Example: UCS from MacAdam Ellipses and CIELUV

Given two printers: Canon PM-970C and Epson MP790

Goal: Reproduce the output of the MP790 on the PM-970C

Construct the uniformization maps for both printers and combine them to obtain the final mapping

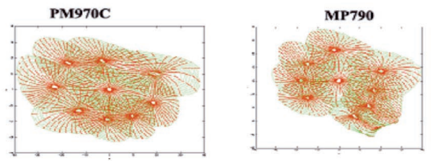

Figure 3. Riemann coordinates system of PM970C and MP790 in CIELAB

Example: Color Weak Correction

The jnd thresholds are measured for a color-weak and 45 color-normals.

The isometry from the color-normal space to the color-weak space is called a colorweak map, which simulates color-weak vision.

Applying the inverse color-weak map to images, the color-weak observer is provide the same color perception of color-normal observers.

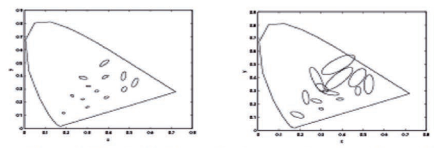

Figure 6 Threshold ellipses of color-normals and a color-weak

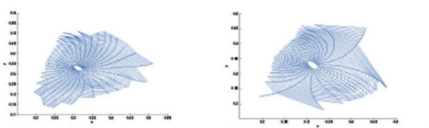

Figure 7. Riemann coordinates of color normals and a color-weak

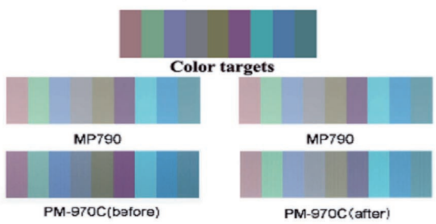

Figure 4 Output of PM970C and MP790 before and after

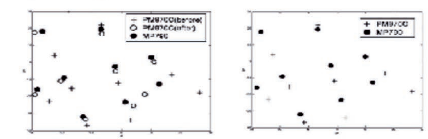

Figure 5 Output measurement of MP790 and PM970C before and after

Figure 8. Color-weak simulated, the original and corrected images by Riemann Geometry