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論　文　要　旨（博士）

論文題目	色信号の統計的性質に基づく色知覚に関する研究

（要旨 1,200字程度）

われわれの視覚入力をつかさどる網膜には，3種類の錐体が存在するが，それらの3錐体により取得できる外界の色情報は限られており，その多くが失われるため，局所的な情報のみによって外界の色を恒常的に知覚することは困難である．

こうした問題を背景に，最近の色覚研究では，シーンの大局的な情報，すなわちシーン統計量が色知覚に与える影響について，議論が活発化している．

たとえば，色信号の平均（Webster et al., 2000ほか）や，分散（Brown-MacLeod, 1997ほか）と色知覚との関係の他，最近では特に色恒常性との関連性について，心理物理実験による現象記述（Golz-MacLeod, 2002）や，計算論的な枠組みからのベイズモデル（Brainard-Freeman, 1997ほか）などが提案されている．本論文では，照明光の変化に対し，恒常的に物体色を知覚する色恒常性，および，ある色を通してその背後にある別の色を同時に知覚する色彩透明視という視覚機能に焦点を当て，シーンを構成する色信号の統計的性質が，視覚系が視知覚を成立させる上で，積極的に利用可能な情報を与えるか，計算論的，心理物理学的に検討した．

また，色彩透明視と色恒常性は，共に色を恒常的に知覚する視覚の機能であることから，その処理機構の類似性についても議論した．

まず，透明物体を含むシーンの物理シミュレーションから，有彩色フィルタに覆われることで，フィルタの色相に依存した平均色のシフトや，色分散，輝度分散が低下に加え，フィルタの色相の情報を反映した，極めて強い輝度-色相関が生じることがわかった．さらに，こうした色信号の統計的性質の変動傾向を模擬した実験刺激を用いた心理物理実験結果は，こうした物理的な色信号の統計的性質の変動を，視覚系が透明性を判断するための手がかりとして積極的に用いていることを示した．

また，色恒常性問題についても，物理シミュレーションで見られた，照明に対する輝度-色相関の堅牢性を利用したベイズ推定モデルを提案し，輝度-色相関がシーンを構成する物体の平均色および照明光の色を推定するための手がかりとなることを示した．さらに，自然画像に対しても，こうした輝度-色相関の堅牢性が存在することを示した．そして，照明光推定に関する心理物理実験結果により提案モデルによる照明光推定結果を評価し，視覚系が色恒常性を成立させるうえで色信号の統計的性質を手がかりとする提案モデルが妥当であることを示した．

本論文は，外界シーンを構成する色信号の統計的性質の変化が，色知覚の成立において有力な手がかりとなる情報を与え，視覚系もそうした情報を積極的に利用していることを示した．

さらに，色覚の処理機構への色信号の統計的性質という大局的な情報の介在という観点から，色彩透明視と色恒常性には類似の処理機構が関与していることを示した．

Color Perception Based on Color Signal Statistics

ABSTRACT

Because our visual system captures the visual information as retinal images compressed to two-dimension, it is difficult to make the constant visual perception only with such incomplete information. Moreover, perceived color can be easily changed due to various illuminant conditions. For example, our visual system can perceive the color of the apple as always red although apparent color of the apple under the yellowish illuminant tends to be orange. This phenomenon indicates that human visual system involves more complex processing mechanisms for achieving the robust color perception. Recent researches about relation between visual perception and scene statistics as global information of visual environment showed that our visual perception is influenced by color signal statistics of scenes such as average or variance (Webster et al., 2000; Brown-MacLeod, 1997 etc.). This thesis aims to reveal the relation between color signal statistics of scenes and human color perception. In particular, this thesis focused on such human vision abilities known as color transparency and color constancy.

First, relation between the statistical property of a color signal and the conditions for perceptual color transparency was investigated by numerical simulations. In this experiment, each scene consists of a surface which is randomly selected color chips from Munsell color databases of measured the spectral reflectances and a transparent filter for a set of plastic filter, and investigated how the color signal statistics of scene overlapped by a transparent color filter will change compared to no-filter scene. Color signals and those statistics (mean, variance and luminance-color correlation) were calculated in DKL color space which is closely related to the human early visual system. As a result, systematical changes of color signal statistics by overlapping a transparent filter were observed. Mean color was changed toward filter's color and mean luminance was reduced by overlapping a transparent color filter. Variance of color signals (i.e. color or luminance contrast) were reduced in contrast to the no-filter scene. In addition, the systematic change of the cross-correlation between luminance and color, related to changes of the mean color, was observed. These result showed that systematical changes of color signals occurs by overlapping a transparent filter. Next, a series of subjective experiment and psychophysical experiment were performed to investigate how

the color signal statistics will relate to perceptual color transparency. Results of the experiments with stimuli that simulated tendency of changes of statistical characteristics of color signals suggest that physical changes of color signal statistics caused without any relation to visual system are used as clue for perceiving transparency. So not only changes of mean or variance of color signals already discussed (e.g. Metelli, 1974), but also systematic change of luminance-color correlation is necessary to perceive a transparent surface. These results showed that human visual system may use the physical changes of color signal statistics caused by a transparent filter as crucial clue perceiving the color transparency.

Next, relation between the statistical property of color signals and color constancy was investigated by numerical simulations, and then Bayesian inference models was proposed, which focuses the robustness of the luminance-color correlation against the changes of illuminants observed in physical simulation. In the simulation, a set of spectral reflectance data of Munsell color chips and artificially generated illuminants of different colors represented by a sinusoidal power distribution with different phases were used to simulate various scenes. Each scene consists of some surfaces which are randomly selected from all hue to generate "gray-world" (GW) scenes and from particular different hue distributions to generate "colored-world" scenes. As a result, mean chromaticity of the observed scene varies depending on both the mean surface colors and illuminant colors, while luminance-color correlation tends to be clustered and does not much vary depending on the illuminant color. This property of the luminance-color correlations is supposed to play an important role in the proposed model, that is, the luminance-color correlation can provide reliable information about statistics of surface color despite the illuminant change. Using such tendency of the variation of color signal statistics, Bayesian inference model was constructed, and a series of numerical experiment were performed to test proposed model. As a result, proposed model can separate the illuminant color and mean object color against the shift of mean color which observed in presented scene. These results suggest that color signal statistics of scene also give a clue for solving the color constancy. In addition, presence of such robustness about luminance-color correlation was also shown with natural images, it was shown that the proposed model is suitable for visual system model achieving color constancy by comparing with result of psychophysical experiment about the illuminant estimation

This thesis concludes that physical changes of color signal statistics caused without any relation to visual system give a clue for achieving the visual perception and visual system actively uses it. Moreover, this thesis showed not only the presence of intervention of the global information such as color signal statistics to color vision mechanisms but also similarity as the processing mechanism of color transparency and color constancy.