# Probabilistic reconstruction of color for species' classification underwater

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Color is probably the most informative cue for object recognition in underwater imagery. Color carries a wealth of useful information– from health of vegetation to identification of debris. However, attempts to use color directly were not very successful. In previous work we have tried to assign specific palettes of colors to corresponding micro-habitats and to estimate their percentages of coverage on mosaics constructed from HD footage collected from an ROV. This approach worked reasonably well, but the key factors of success were constant ROV altitude and flatness of the seafloor. Each set of mosaics requires manual selection of different palette. Thus, light absorption in the water column remained a constant, albeit unknown factor. Similar approach in a setup where imagery had significant range of depths failed dramatically. The main reason for this is that objects usually have relatively complex spectral signatures (dependence of reflectivity on wavelength) and it is intuitively clear that just three measurements (R, G, and B channels) are not sufficient to reconstruct original (as if imaged in air) color. Thus, depending on current water properties, illumination, range to the target, intrinsic diversity of spectral signatures within the class of targets (species) that need to be classified, and properties of the sensor (camera) itself, recorded color may vary in an amazingly wide range.

To demonstrate this variability a numerical experiment has been conducted. Color forming process is nonlinear and involves integration over visible spectrum of the product of functions describing spectral dependencies of a light source, object reflectivity, light absorption in the medium, and camera sensitivity function. Certain spectral signature for the observed object was chosen, and then trichromatic color at known distance in water with given properties was calculated. To prove ambiguity of color restoration it is sufficient to find another spectral signature which leads to exactly the same recorded color (with the same imaging range, and camera and water properties). These signatures could be found only numerically. Images below demonstrate some of these cases (see caption for explanation). These examples alone demonstrate unreliability of the attempts to recover the original color with light propagating through water.

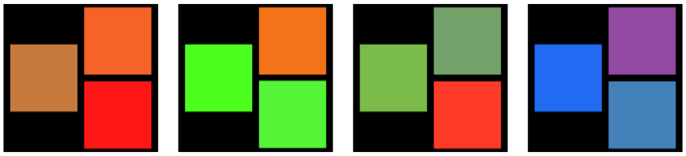

*Figure 1. Demonstration of ambiguity of underwater color restoration. All colors have their brightness normalized. Left squares: color recorded underwater. Right squares: colors recorded in air, appearing underwater as a left one.*

Monte Carlo search for distribution of original colors appearing similarly underwater leads to an example shown in Figure 2. The search was performed as follows. The spectral signature was chosen to belong to certain family of curves in a (brightness, wavelength) space. Integration of this signature multiplied by appropriate functions leads to a certain trichromatic color. This color is converted from RGB space to CIE L*a*b* space, and the L-component (luminosity or brightness) is being dropped. The corresponding color underwater can be found using the same integration, but with additional function as a multiplier – wavelength-dependent absorption. On the $a * b *$ chart this sensor-recorded color

$(a*, b*)_w$ is shown as a black circle with a red slanted cross. The chart background is colored according to the appropriate a*/b* combination (with arbitrary L-component) for visualization purposes.

The search is conducted in a 9-dimensional space. If a resulting combination $(a*, b*)_a$ led to the color sufficiently close to $(a*, b*)_w$, the chart in Figure 2 was marked with a black dot.

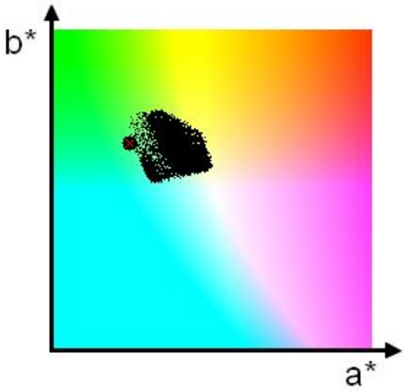

*Figure 2. Distribution of a*b* components of colors leading to the same color recorded by a sensor underwater.*

Distribution of dots in Figure 2 is actually a probability density function (PDF) related to an observation marked by a crossed circle. In other words, for a given observed color PDF gives the probability of a true color of a target. Unfortunately the relationship is so complex and involves so many other nonlinear functions which can be determined only empirically that this knowledge is of little use. Besides, this distribution is valid only for a specifically chosen functions describing light source, quantum efficiency curves, etc. In reality all these functions have to be known and must be monitored constantly (for example, sunlight or water properties).

The best way to classify an underwater scene would be to acquire spectral signatures on a regular spatial grid of points. This is, however, impossible for a number of reasons. In this paper we report about the approach allowing to classify RGB imagery routinely collected underwater. This approach requires information about the species of interest (family of spectral signatures), source of illumination (ambient or artificial), light absorption in water, and sensor response. Camera and light source properties are calibrated in the laboratory conditions. Ambient light and water properties are measures *in situ*. Spectral signatures of expected types of species are collected in advance *in situ* too and constitute the reusable catalogue. As it was shown above, 100% reliable reconstruction of the true color for each pixel of the imagery is not possible. However, it is possible to estimate a probability of a pixel to depict certain class of species. In many cases it is sufficient to build an informative classification map.

We report about the design and development of the specialized device for collection of spectral signatures and results of its testing.

Session “Optical and Acoustic Mapping”, Fausto Ferreira and Nuno Gracias