Investigating Human and Computer Performance in Color Comparison for Coral Bleaching Monitoring

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Abstract

The occurrence of coral bleaching events in recent years motivates the deployment of timely and localized citizen science programs for coral reef monitoring. This work investigates the use of color cards for coral bleaching event monitoring and presents an image processing application [1] that attempts to improve upon the consistency and accuracy of human efforts in color comparison tasks. In particular, the work builds upon the efforts to create a Hawaiian-specific color card - the Hawaiian Ko'a Card - and investigates human performance and computer performance in assigning ratings to in-situ coral specimens.

The results of this work presents evidence of robust human performance in utilizing the card, a full end-to-end image processing pipeline for coral-color card comparison, and a discussion on improving citizen science efforts with respect to coral health monitoring.

1. Introduction

Coral reefs are highly productive and incredibly biodiverse marine assets that create billions of dollars in value through tourism, coastline protection, fishing, and scientific research[5]. Recent years have bore witness to mass coral bleaching events, where coral polyps expel the endosymbiotic algae they contain in response to environmental stress factors such as increased water temperature, increased solar irradiance, and exposure to certain pollutants[9]. The increase in average temperatures due to global warming is the leading contributor to such bleaching events [12] [8] and will continue to exacerbate such phenomena in coming years. Bleaching often leads to coral death and thus the loss of critical environmental services and natural resources which coral reefs provide to human societies and economies.

Monitoring coral reef health is critical in building better predictive models for such bleaching events. Although such monitoring efforts exist at larger scales via remote sensing tools [11], more localized efforts can improve spatial monitoring resolution.

Citizen science programs have increased in popularity in the past decade [18] and are promising candidates to help tackle localized monitoring of coral reefs at scale. Since the expulsion of coral symbionts coincide with a loss in photosynthetic pigments, the color of a coral specimen serves as a marker for bleaching extent and intensity, with the color "white" serving as a fully bleached coral specimen (hence the name bleaching). [21] The relative ease of observing color motivates the deployment of citizen scientists to monitor coral reef color for evidence of bleaching. Use of color card containing color patches meant for comparison to an external object has been used to standardize color observations by volunteers. One such program has been particularly successful in Australia [19] and a new color card is under development by the Coral Reef Ecology Lab at the Hawai'i Institute of Marine Biology in O'ahu. [4]

Differences in human color perception among different demographics [16] and even societies [20] pose an interesting challenge for standardization among observers. This motivates the development of a field deployable technique that promises more consistency. The progress of computer vision capabilities and the widespread availability of low cost image sensors [1] allow an image processing application to replicate human performance in multiple visual tasks such as labeling[10] and segmentation[14]. However, underwater image processing brings about its own challenges with issues involving light attenuation and the loss of portions of visible spectra in the water column. [1] Furthermore, corals are difficult subjects for visual tasks such as semantic segmentation due to inter-class variation, occlusion, and dense spatial groupings. Color comparison is also a challenge due to non-uniform sensitivities of human color perception, different color representations in different color spaces, and extraction of dominant colors given a complex

[1] https://github.com/eldrickm/koa-tool

scene.

This work will investigate human performance in color perception and the use of the Hawaiian Ko'a Card, introduce an image processing application to achieve more robust performance in analyzing corals with the Hawaiian Ko'a Card, compare the performance of humans and the application, and discuss the implications of such a study on bolstering citizen science efforts for coral bleaching analysis.

2. Research Goals & Hypothesis

The work centers around the use of the Hawaiian Ko'a color card to evaluate the extent of bleaching in Hawaiian coral reefs and aims to accomplish three major goals:

1. Evaluation of variance in human perception of color with respect to the use of the Hawaiian Koa Card in quantifying bleaching in Hawaiian coral species.

2. Development of a computer application to automate analysis of bleaching in images of Hawaiian coral species.

3. Improvement of citizen science methods with respect to coral bleaching analysis.

In relation to the project goals stated above, the following hypotheses are proposed:

1. Significant variance in color rating by humans will be observed in the use of the Hawaiian Ko'a Card. This result will motivate the development of a computer application for more consistent and accurate color analysis for coral bleaching.

2. The use of deep learning methods and modern computer vision techniques in the digital analysis will allow more consistent and accurate color analysis for coral bleaching.

3. The development of a computer application can increase effectiveness of coral reef monitoring.

3. Methods

3.1. Hawaiian Ko'a Card

This work heavily uses the Hawaiian Ko'a Card (Figure 1) developed by Dr. Keisha Bahr at the Coral Reef Ecology Lab in the Hawai'i Institute of Marine Biology. [4] The card is subdivided into 36 10 degree arcs which each have a color value. These color values correspond to a measure of zooxanthellae counts and chlorophyll levels specific to Hawaiian coral species. Volunteers are intended to bring a waterproof version of the card into the water and compare coral colors to values on the card, noting the lightest and the darkest colors present on the specimen to account for natural color variation among coral polyps.

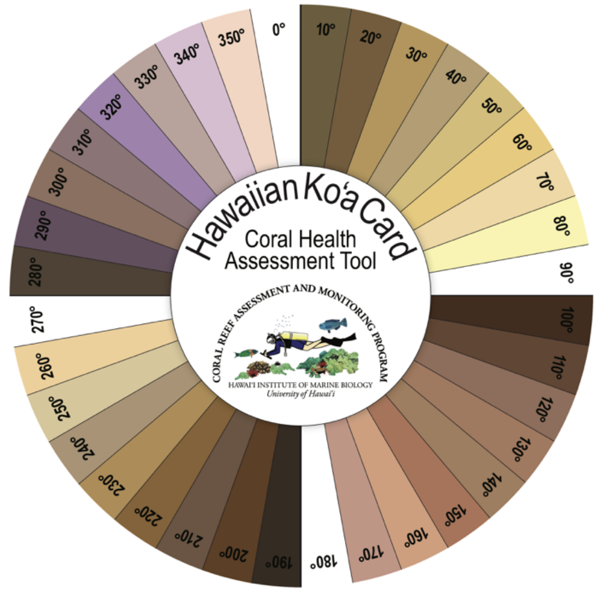

Figure 1: Hawaiian Ko'a Card prototype

3.2. Human Perception Analysis

In order to investigate human color perception, two methods were employed. First, a hue acuity test was first administered to gauge the overall visual acuity for volunteers. Second, five volunteers collected color ratings using the Ko'a Card near the Kohala Coast of Hawai'i Island.

The volunteers who participated in this work consist of 18 students from Stanford University and 5 teaching staff members from Stanford University. All volunteers were participants in the Stanford University Wrigley Field Program in Hawai'i 2018.

3.2.1 Farnsworth-Munsell 100 Hue Test

The Farnsworth-Munsell 100 Hue Test (Figure 2) is used to quantify color vision accuracy and test for color blindness. Observers arrange four rows of 25 tiles based on color hue. The test is scored with respect to the number of incorrect tile placements, with a lower score corresponding to higher visual color acuity. 18 students and 5 teaching staff members participated in the test, in evening hours (8:00 PM onwards). The test was administered on a MacBook Air 13-inch Early 2014 model at full brightness with soft-white fluorescent lighting (approx. 2700K).

3.2.2 Ko'a Card Data Collection & Field Protocol

Color ratings for coral using the Ko'a Card were collected at two locations: Māhukona (20.1837, -155.9008)

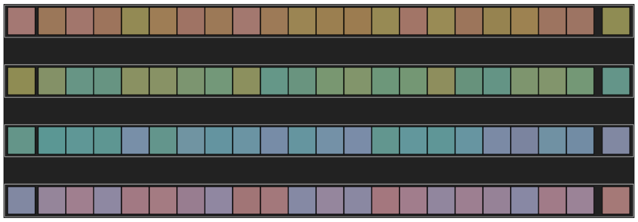

Figure 2: Farnsworth-Munsell 100 Hue Test color tiles

and Spencer Beach (20.0239, -155.8226) on the Kohala Coast of Hawai'i Island. Data was collected in the morning, 9:00 AM and 10:45 AM respectively, by five student volunteers. The data was collected under low wave action, sunny conditions with superb visibility at Māhukona and poor visibility at Spencer Beach. Coral specimens were selected at each site during a 60 minute and a 30 minute swim respectively. Specimens were selected if they were alive, in-sight, and relatively intact. Specimens were gathered at depths from 1 to 4 meters according to volunteer self-reporting. Volunteers were asked to report the dominant color shade for a coral specimen and collected a singular color value on the Ko'a Card. 9 specimens were rated at Māhukona and 3 specimens were rated at Spencer Beach. Volunteers were read a script before entering the water and briefed on how to use the color card but were not subject to specific or intensive training in color card use before hand.

3.3. Computer Perception Development

The development of the computer perception stack required solutions to multiple problem domains, which are outlined below. Three sets of images were captured, with the first two collected at an early date for use in application development and testing, and the final set gathered during the volunteer excursion that correspond to specimens rated by humans. The application is developed in Python 3.6 using OpenCV, the numpy/scipy stack, and DEXTR, the state-of-the-art in interactive segmentation [14].

3.3.1 Image Capture & Field Protocol

Images were captured immediately after the rating of a coral specimen by the volunteers. The image processing pipeline requires the Ko'a Card to be in the scene. Techniques to do so involved holding the card at arms length to match with coral depth or placing it beside the coral on the benthic floor if there was sufficient space. This can prove to be difficult with strong wave or ocean current action, as the card will frequently move out of place or turn away from the camera. Great care was taken to try and encapsulate a representative part of the coral in the scene and keeping both the card and the specimen out of shadow. In order to accurately model

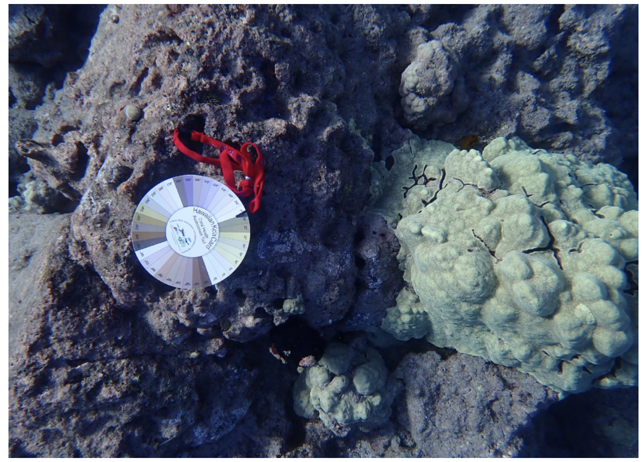

Figure 3: Scene image with Ko'a Card and specimen

the lighting conditions of the coral, the Ko'a Card must be placed near the same depth of the specimen, ideally adjacent to it. Images were captured with the following equipment and settings:

- Olympus Tough TG-5 4K
- F2.0
- Underwater Snapshot Setting
- ISO Auto
- Auto-Focus

3.3.2 Color Card Localization & Homography

In order to account for color and lighting issues underwater and make representative matched, the Ko'a Card must be in the image scene next to the coral specimen. This assumes that the Ko'a Card and the coral specimen will be subject to the same lighting conditions when spatial distance is minimized. This thus allows direct in-scene comparison of Ko'a Card color values and coral specimen color values without the need for color correction.

Localizing the Ko'a Card is achieved through the use of a Binary Robust Invariant Scalable Keypoint (BRISK) feature detector and descriptor [13] and a brute force matcher in the OpenCV framework. Feature detection and description is the process of searching for points in an image that can be used to identify it. Feature matching involves matching features in a query image (a downscaled 500x500 image of the Ko'a Color Card) to a scene image (containing our coral) that contains the query image subject to rotation, scaling, and other affine transformations in 3D space. Successful mapping allows the construction of a homography matrix

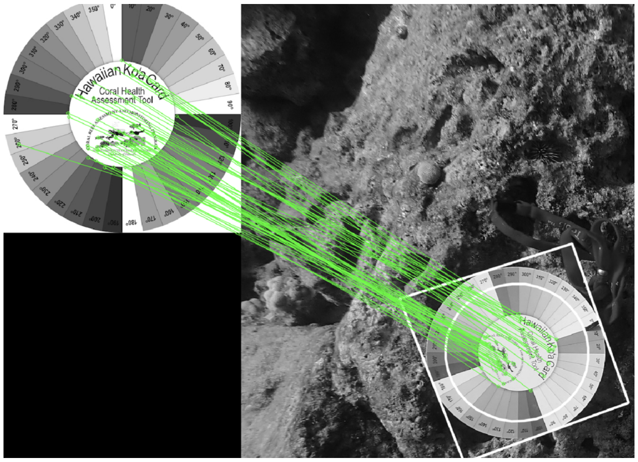

Figure 4: Feature matching and homography for color card localization

that maps points in the query image space to the scene image space.

Retrieving Ko'a Card color values for comparison involves using the homography matrix to map 36 points in the middle of each color arc in the query image to corresponding points in the scene. This allows the retrieval of in-scene Ko'a card values that are subject to the same lighting conditions as the coral specimen, improving accuracy of color comparison.

This method is quite robust, with only one scene image of the twelve gathered failing to retrieve sufficient feature matches to robustly create a homography matrix. In the case of failure, the user is asked to select the 36 sampling points in the scene by hand.

3.3.3 Coral Localization & Segmentation

In order to retrieve the color of the coral for comparison to the Ko'a card values, a region of interest is specified by the user. The user selects four boundary points on the image, which is given the the DEXTR image segmentation architecture [14]. An image mask consisting of boolean values with the same spatial dimensions as the input image is returned, allowing the selection of pixels which belong the region of interest. This method is used to isolate coral specimens from occluding object, the background, and other non-specimen objects. Despite the fact that DEXTR was not trained on segmenting corals, it has robust performance with near or on-par human performance.

3.3.4 Color Correction

A color correction technique [2] was attempted with the assumption that colors on the Ko'a card could be used as reference color values from which the entire scene could be corrected. Assuming that changes in color profile and lighting are linear, a least-squares problem can be formulated with reference (known) color values and scene color values with the form $A_c x_c = b_c$, $c \in \{r, g, b\}$ where c notes the three RGB channels, x_c is a 36 by 1 vector of observed channel values of Ko'a card shades, b_c is a 36 by 1 vector of known channel values of Ko'a card shades, and A_c is a set of coefficients that are adjusted to minimize error between a_c and b_c. Given A_c, all pixels within the image can be properly corrected. Unfortunately this led to interesting color artifacts and unsatisfactory color profile adjustment, largely due to the fact that the scene was subject to multiple light conditions, colors on the card fail to represent all of the colors in the scene, and changes in RGB values were non-linear.

Figure 5: Segmentation using DEXTR and boundary points

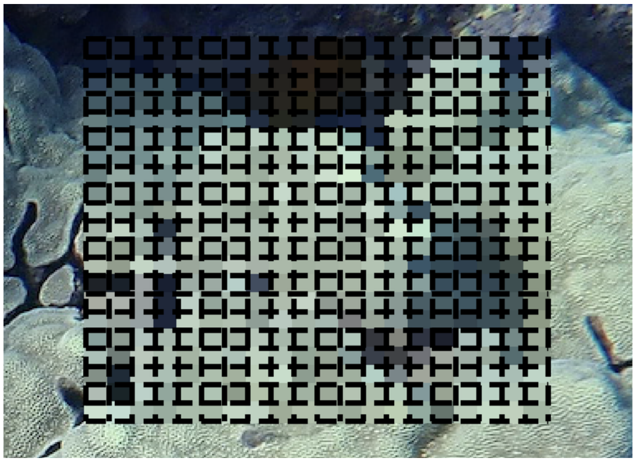

Figure 6: Color extraction of partitions

Figure 7: Uncorrected partitions (top) vs shadow corrected partitions (bottom), compared to original image.

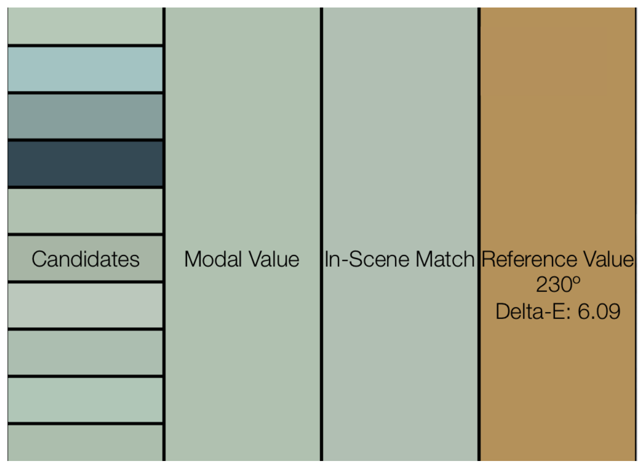

Figure 8: Candidate matching

3.3.5 Color Extraction

A bounding box with padding is drawn around the region of interest. The interior of the box is split into 20 by 20 partitions. Within each partition, a k-means clustering of color [2] is performed with k = 3. The cluster with the most points is selected as the dominant color. Furthermore, each partition receives a weight corresponding to the amount of coral (given by the image mask) present within a partition. This weight ranges from 0, in which the partition contains no coral pixels, to a value of 1 which indicated the partition is fully filled by coral pixels.

3.3.6 Shadow Correction

A significant problem encountered during color extraction is the inclusion of regions in shadow, which darkens the dominant color of a partition during color extraction. This can be particularly important for coral species that have branching morphologies with crevices such as *P. meandrina*, the cauliflower coral. Otsu's method for thresholding [17] is used to separate valid pixels and shadow pixels with the intuition that within a partition containing shadow regions, pixel luminance follows a bimodal distribution. Otzu thresholding find the best point to separate the distributions and thus the k-means clustering utilizes only non-shadow pixels.

3.3.7 Color Matching

With 36 in-scene Ko'a Card color values and a set of dominant colors, a set of random partitions above a certain weight threshold is selected. For this work, 10 random partitions are used as candidates with weights greater than 0.75. These candidate colors along with the 36 reference colors are transformed from RGB space to CIELAB space and are compared using the delta-E color distance measurement. [3] The most common matched color card value among the 10 candidates is used as the final color value decision.

3.4. Citizen Science Contributions

3.4.1 Datasheet Design

In order to gather field data, a datasheet was designed which accounts for depth, species, morphology, color rating, and a bleaching estimate of a coral specimen. This is included in Appendix A.

[2] https://adamspannbauer.github.io/2018/03/02/app-icon-dominant-colors/

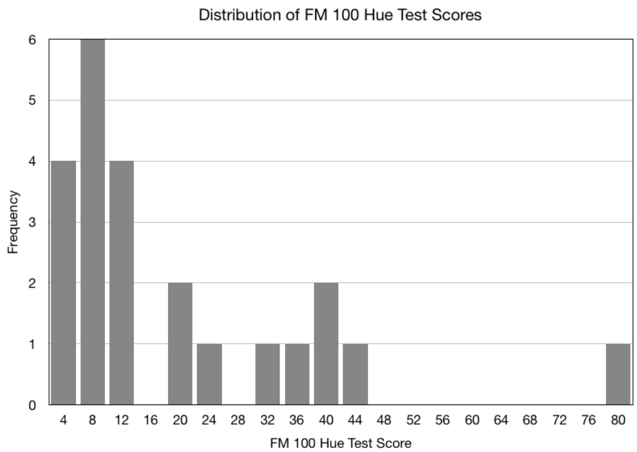

Figure 9: Overall FM100H Test Results

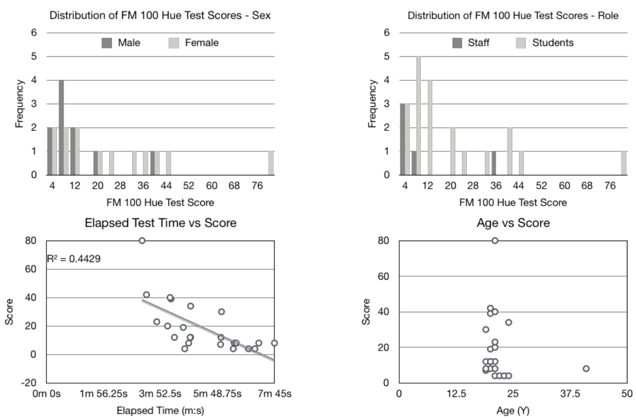

Figure 10: Disaggregated FM100H Test Results

3.4.2 Field Protocol

An instructional script was drafted for use in relaying instructions to a group of volunteers before an outing. This is included in Appendix B.

4. Results

4.1. Farnsworth-Munsell 100 Hue Test Results

The overall FM 100 Hue Test distribution in Figure 9 points to a particularly high-discriminatory ability within the volunteer group, with an outlier at 80. Previous work has shown that mean scores range from 7 to 10 with standard deviations of 2.4 and 2 respectively. [15] This shows strong visual acuity among a significant portion of students. However, the mean and standard deviation of the sample excluding the outlier at 80 ($\mu = 16.3$, $\sigma = 12.8$) is affected negatively by relatively poor performance by a third of the sample.

The time elapsed until completion of the test (Figure 10, lower left corner) shows a strong correlation with performance ($r^2 = 0.44$, $p << 0.05$). This is intuitive, as more careful and longer deliberation likely leads to better discriminatory performance. This implies, with respect to the use of the Ko'a Card, that longer time underwater deliberating and comparing can possibly increase quality of volunteer observations.

4.2. Human Ko'a Card Data Collection Results

Figure 11 shows the set of human color ratings for the 12 specimens rated. We can see that human performance is solidly robust with at least one match per specimen among two raters. Some specimens have more than two ratings in agreement and Specimen #7 shows full consensus. In the same vein as the Law of Large Numbers or Linus's Law [3], more ratings for corals at a site will likely improve accuracy and consistency of monitoring efforts. Additionally, robustness of human performance alleviates an immediate need for novel methods to increase consistency or accuracy of coral ratings.

4.3. Human-Computer Comparison

Figure 11 compares the computer ratings and shadow corrected computer ratings with human ratings. A comparison with the image in context is given in Figure 12. An additional full pipeline demonstration is shown in Figure 13 We can see that the computer is subject to pick darker shades, likely due to the influence of shadows. Surprisingly, shadow correction does not lead to many differences in dominant shade. This issue motivates a need for more robust shadow effect elimination.

5. Discussion

5.1. Generalizability of Results

The demographics of the volunteer population (mostly early-to-mid 20s) as well as their status as students at a private institution with some amount of training in Hawaiian coral identification calls into question the generalizability of results in this work. However, it can be argued that in this context, many potential citizen scientists are able-bodied (able to swim, comfortable in the ocean) and the introduction of training programs to decrease observation variability allows comparison between the volunteer group and other potential groups.

[3] In software engineering: "Given enough eyeballs, all bugs are shallow."

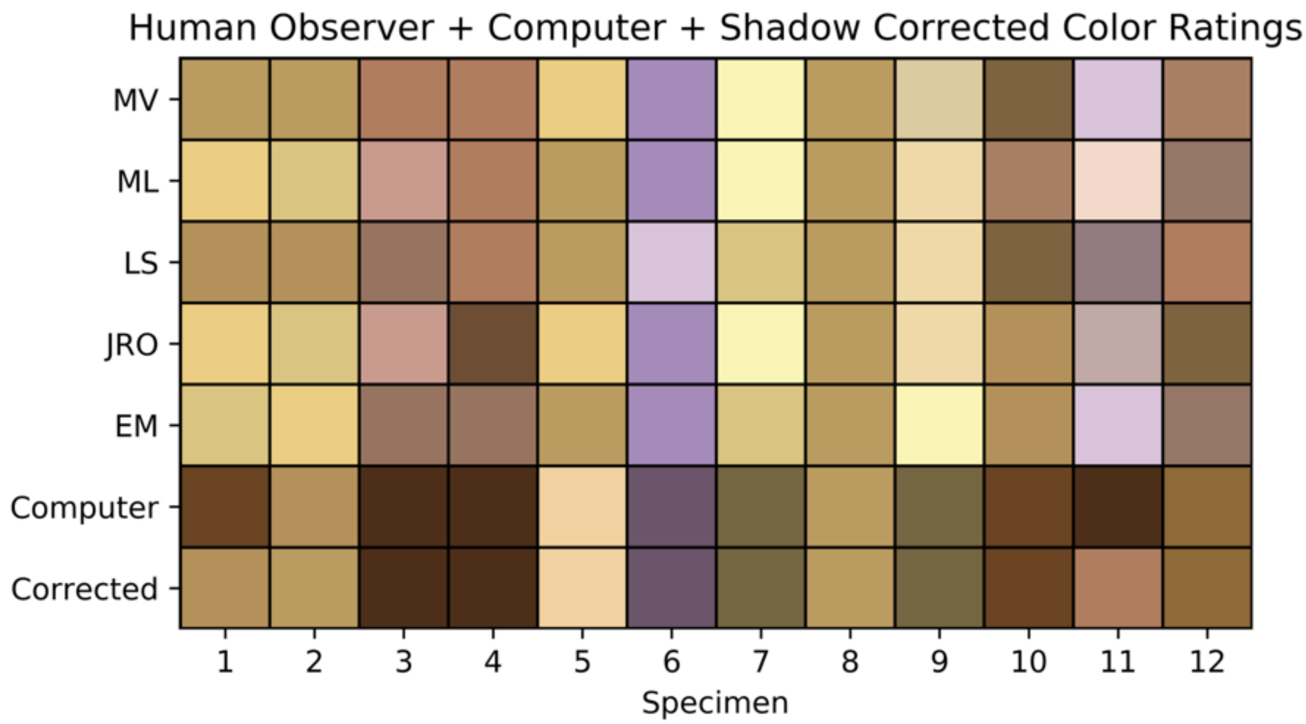

Figure 11: Human and Computer Color Ratings across 12 coral specimens.

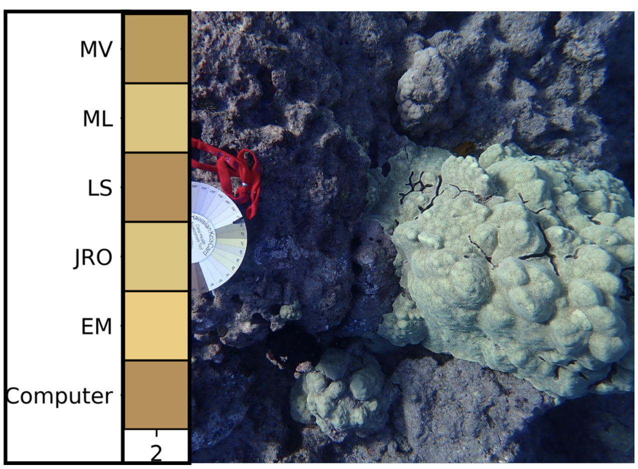

Figure 12: Color ratings of humans and computer for specimen in Figure 3 and Figure 8

5.2. Robustness of Human Perception

The robust profile of color observations across the volunteer group is strong evidence against the initial hypothesis of strong variation among human perception. Humans are able to effortlessly undertake many of the computer vision tasks needed to recreate performance such as automatic white balancing [7], ability to identify card location and coral location, and the ability to quickly compare colors. The weakest number of matches however occurred for specimens #10-12 under poor visibility conditions. Such conditions could perhaps motivate the use of computer analysis or additional lighting hardware (such as a submersible lamp) to improve human performance.

5.3. Computer Perception Challenges

The most significant barrier to satisfactory computer performance seems to be the calculation of dominant colors and comparison across a color space. More robust shadow elimination and more refined color comparison techniques are a promising avenue to improve the existing application.

5.4. Ko'a Card Improvements

As of this writing, the Ko'a Card is in a prototype stage. The following serves as a list of possible improvements or changes that could help improve its function:

- Elimination of redundant shades
- A more robust volunteer attachment system, such as a reinforced wrist strap hole to prevent card damage.

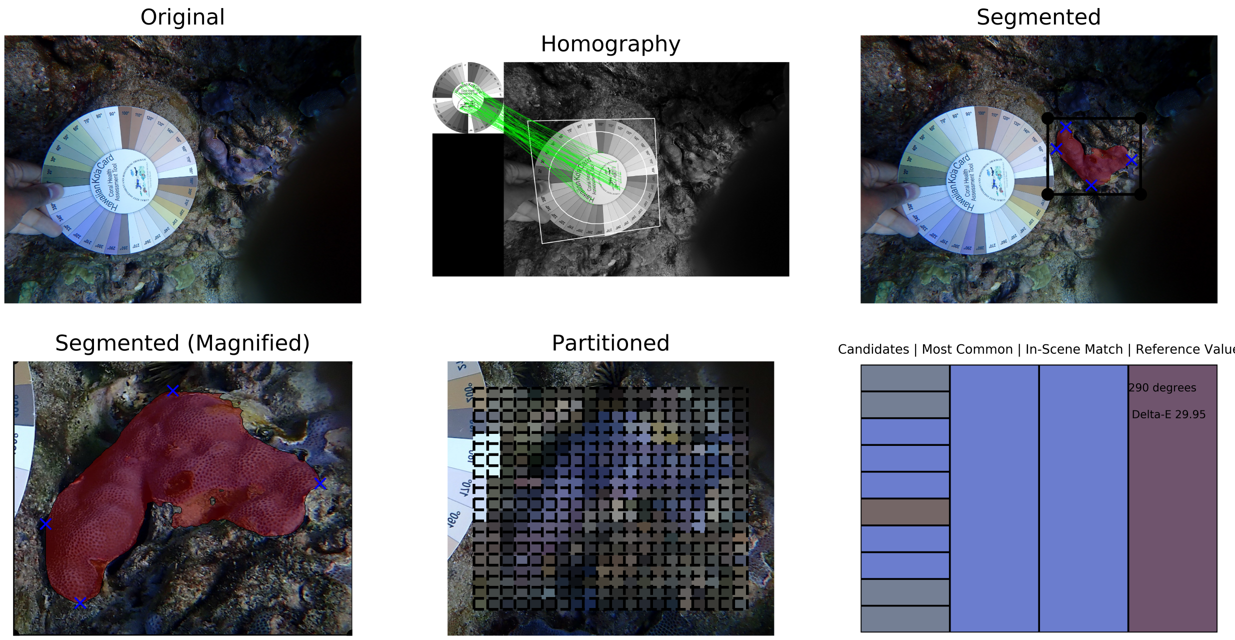

Figure 13: (
The full image processing pipeline with shadow correction)

- Inclusion of a fiducial mark [6] on the front face to allow easier localization and homography

5.5. Future Work

Despite the initially weak performance of the application, an improved image processing pipeline could serve as a force multiplier for citizen scientists by offering an avenue for more complex image analysis such as bleaching quantification per sector, etc. Further improvements also include automated patch labeling, whereby regions of interest are automatically chosen by the computer based on its ability to identify coral textures. Current capabilities should exist but was outside of the scope of this work due to difficulty of accessing a labeled dataset and having computational resources to train such a network. The compilation of coral images with labeled color values could prove to be a valuable dataset on its own given sufficient participation, perhaps unlocking the potential for a fully end-to-end convolutional network to predict coral color based on any arbitrary picture. Finally, the ability for the program to produce a detailed report for review by external agencies (such as the Eyes of the Reef Network [4] in Hawaii) is an important future direction in order to produce actionable reports from a massive amount of data.

[4] https://eorhawaii.org

6. Conclusion

This work has explored human color perception ability, the development of a computer vision system to emulate human performance, and how such efforts can help improve citizen science efforts with respect to monitoring coral bleaching events. The results show robust human performance and reveal challenges in computer-based analysis, particularly in qualifying color distance and ignoring shadow effects. Despite such issues, a computer-driven approach can help increase consistency and repeatability for reef monitoring and holds the promise of an end-to-end solution that can take advantage of volunteer-gathered data. Such technology could be used in continuous monitoring programs such as the deployment of solar-powered drifting cameras that perpetually monitor coral reefs. Overall, harnessing both novel technologies with an influx of citizen science enthusiasm can improve how scientists and engineers can monitor and model the natural world.

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Appendix A

Hawaiian Ko'a Card Datasheet (v1.0)

Name / Sex [M/F/O] / Age:						
Date [MM/DD/YYYY] / Time (HH:MM - 24 HR):						
Sites:						
*Note: Please encode **site name**, **coordinates**, and **conditions** above in following format: **[Puako Bay, 19.5873 N 155.5023 W, Cloudy], […], …***						
*Note: Please encode **Morphology** below in following format: **(M)**ounding, **(B)**ranching, **(C)**olumnar, **(P)**late-like, **(E)**ncrusting, **(F)**oliaceous, **(S)**olitary*						
Specimen #	**Site**	**Color Rating (e.g. 180º)**	**% Bleached**	**Species (if known)**	**Morphology**	**Depth (m)**
1						
2						
3						
4						
5						
6						
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9						
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12						
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Notes:						

Questions?: eldrick@stanford.edu

Appendix B

“Welcome to the Ko’a Card Citizen Science Program! This is a brief introduction into the tools we will be using today and how we’re going to gather data safely, accurately, and efficiently. Please feel free to ask questions at any time.”

[Handout Datasheets]

“The data sheet you have in your hands has two main sections - the metadata header above the gray line and the data collection space below it.

In the header section, you will enter full name, sex, and age in the entry boxes.
For sex, please write M for Male, F for Female, or O for Other if you wish to specify further, or leave blank if you prefer not to state.
For date, please follow the format stated on the page.
For sites, please follow the format stated on the note below the Sites line. For multiple sites, please also enter corresponding dates and time on the Date / Time entry box.

I will be providing site information before every excursion into the water

In the data collection boxes please note the Morphology encodings - just enter the bolded letter for each specimen entry. As a volunteer, you will be responsible for using your best judgement to determine the color rating, percent bleached, species, and morphology of each coral specimen we rate.”

[Show Hawaiian Ko’a Card]

“To help in your color rating, we will be using the Hawaiian Ko’a Card developed by Dr. Keisha Bahr from the Coral Reef Ecology Lab in Oahu. This card is a circle subdivided into 10 degree arcs colored in with a certain shade. You will be comparing the color of the coral specimen with the shades on the color card. You will write down the lightest and the darkest shade you see on the degree value on the datasheet. Again, you will be giving a range by specifying two values.”

[Show Common Hawaiian Corals Image]

“This is a picture of common Hawaiian corals that you may see while you are out there. Note the species name and the corresponding morphology.”

“Please fill in your header boxes now.”

[State Site Location, Coordinates, and GPS]

“We will be going to depths of approximately 5 and 10 feet or 1.5m and 3m respectively. I will identify a specimen to rate and we will take turns using the color card to *independently* rate the specimen. Please do not share ratings during this process as it is critical that these estimations are independent across individuals. When all individuals have finished rating a specimen, I will then dive down and take a picture with the color calibration card and Ko’a card. We will then proceed to the next specimen.”

“Please notify me if any of you all are experiencing difficulties in collecting data or more importantly, swimming. If you feel unsafe at any point, please notify me and we will go back to shore as quickly as possible - safety is a priority in the ocean.”