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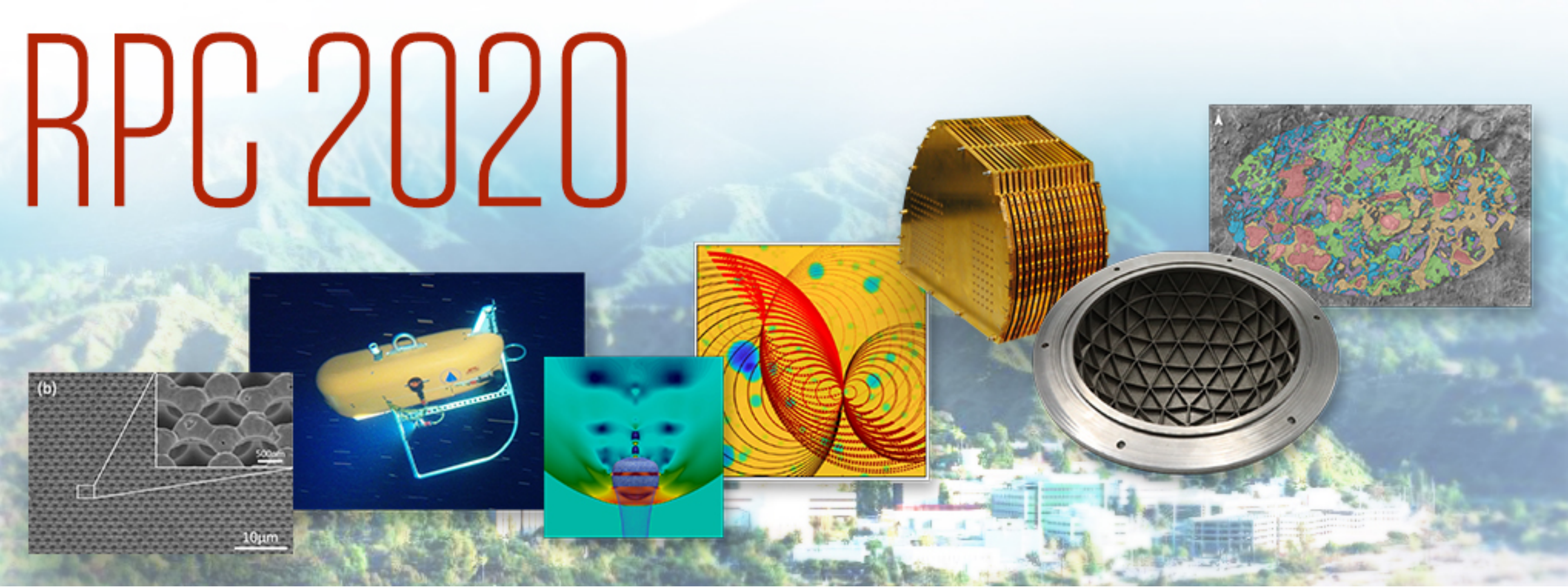

Virtual Research Presentation Conference

Automated Mapping and Planning to Improve Assessment of Coral Reef Health

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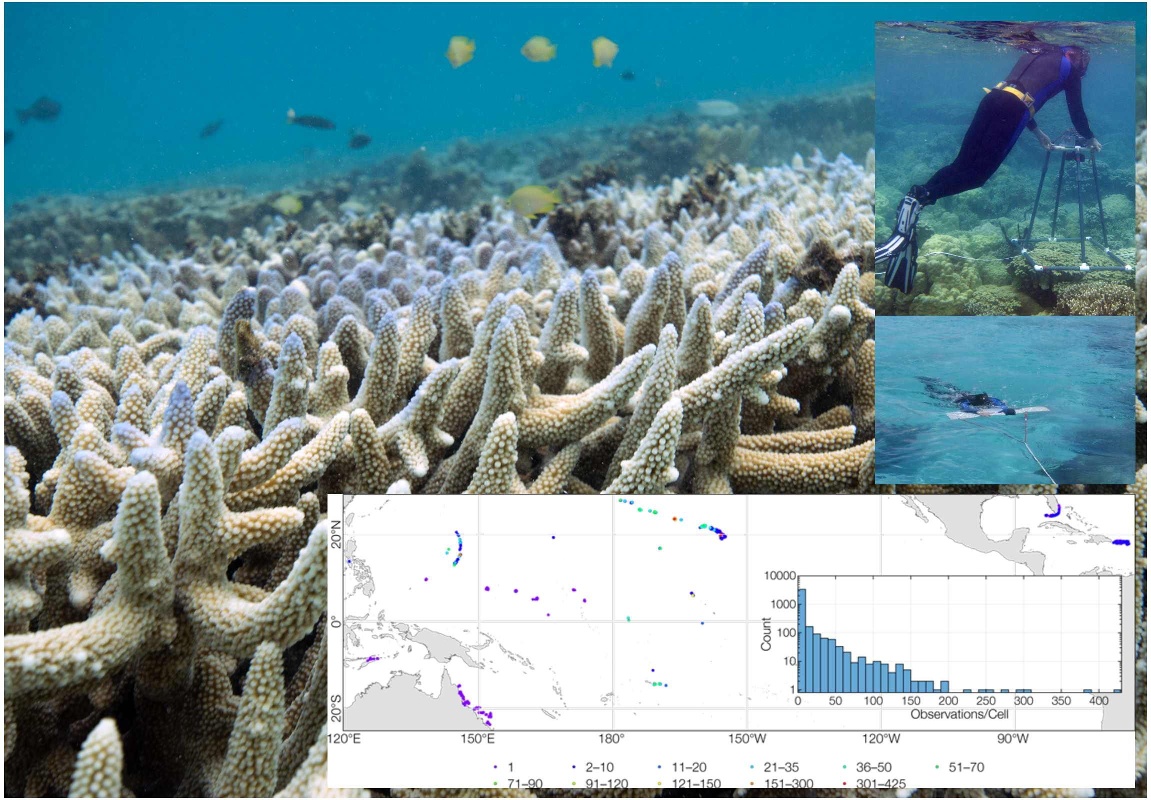
Tutorial Introduction

Abstract

This project will develop technologies for automating data analysis and mission planning of coral reef ecosystems. This strategy represents a fundamental change in how we understand coral reefs and assess their health. Instead of small, infrequent, uncorrelated studies of isolated locations, we will begin to measure coral reefs globally, updating often, and seeing worldwide patterns.



Problem Description

- There is great concern about the current and future state of reefs, which provide ecosystem goods and services estimated near $10 trillion annually [*Costanza et al. 2014*] to hundreds of millions of people around the world
- Current reef assessments and predictions rely upon human in-water survey techniques that are laborious, expensive, and limited in spatial scope, limiting the world's reef area quantitatively studied to approximately 0.01–0.1%
- The result may not be representative of the reef under study, nor representative of global ecosystems
- This investigation advances the state of the art in site mapping of coral reef ecosystems
- The advantages of the proposed approach are that 1) machine learning will enable global understanding by extrapolating a few, carefully selected diver measurements, along with remote imaging spectroscopic measurements; 2) divers will get specific guidance on most informative measurements to collect; 3) methods apply directly to autonomous underwater vehicles to determine where and by what route to collect the optimal set of coral measurements to validate large scale models
- This investigation aligns with the needs and directions of NASA and their missions (e.g., CORAL and SBG); JPL technical capabilities in aquatic systems (e.g., CARACaS) and cross-lab expertise (robotics, autonomy, and science)

Methodology

- The method of hypothesis mapping begins with a priori information, such as wide-area remote sensing data *[Candela et al. 2017]*
- It estimates the information value of new samples with respect to the remote sensing interpretation, using metrics including maximum entropy or mutual information
- As samples are collected and interpreted the value of information in remaining actions is reevaluated so that the plan dynamically adjusts to new information
- The outcome is that the minimal, most informative sequence of actions is taken to maximize the accuracy of the remote sensing interpretation
- In this way, we can take fewer measurements but produce a better model

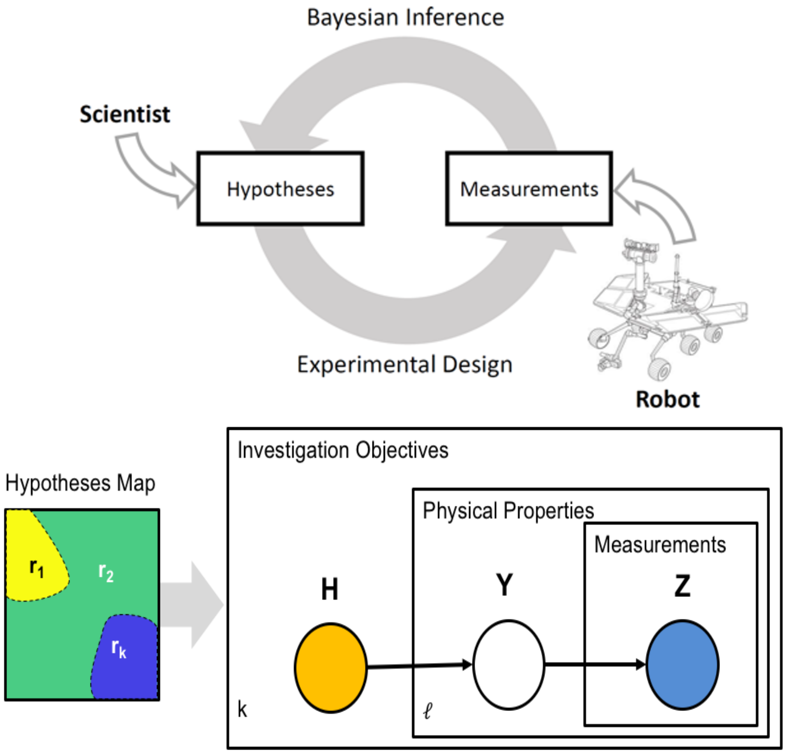


Figure 1. *Hypothesis mapping method (top) begins with scientist generated hypotheses encoded as a map of potential class boundaries, for this case the location of coral, distinguished by health condition and possibly by family/species. These hypotheses and associated likelihoods lead to an experiment design that specifies sampling locations. When those measurements are collected, Bayesian inference is used to refine map and the process continues. The hypothesis map (bottom) is a spatially distributed class likelihood function, P(H|Z), and Bayesian inference can be applied to update the hypothesis (H) through classification of spectra (Y) given the measurements (Z).*

Results

- We have made significant progress in **Year 2,** utilizing the coral reef data sets and probabilistic models created in **Year 1** to 1) develop planning algorithms for coral reef sampling (ME - Maximum Entropy; IG - Information Gain), and 2) evaluate informed planning algorithms (ME and IG) in simulations
- Informed planning algorithms consistently outperform random strategies
- Informed planning algorithms, together with previous probabilistic models, allow for accurate spectral reconstruction and coral reef mapping, outperforming typical scuba diving methods

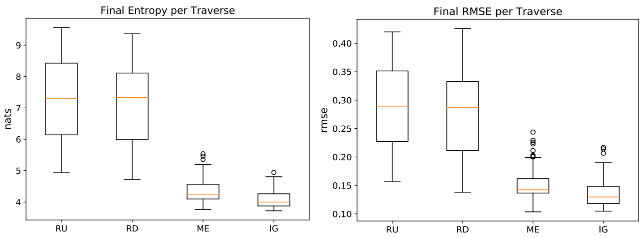


Figure 2. *Final entropy (top) and reconstruction error (bottom) box plots. IG is the best planner, followed by ME. RU (random uniform) and RD (random distance) perform notably worse.*

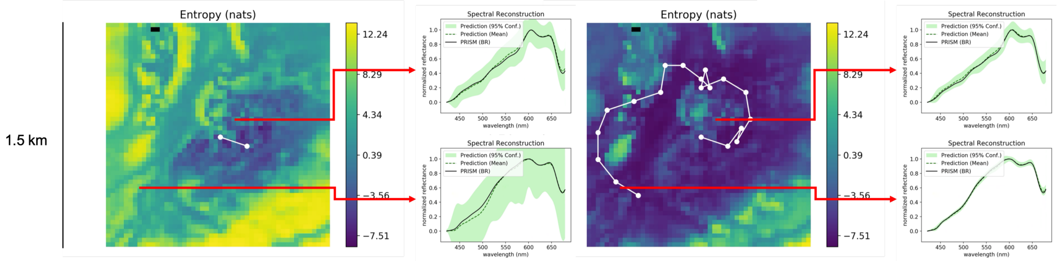


Figure 3. *Entropy (uncertainty) maps and spectral predictions at the beginning (left) and at the end (right) of a simulated traverse.*

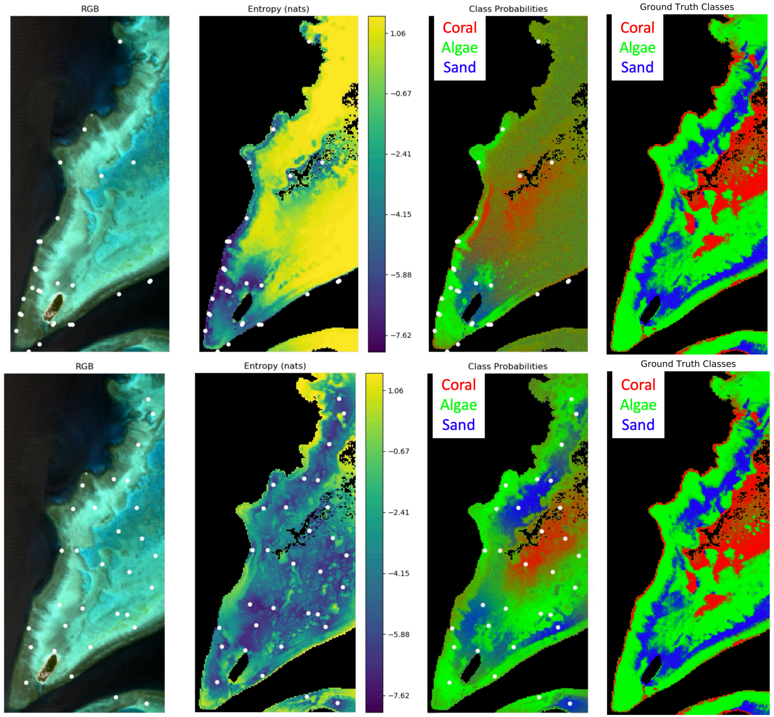


Figure 4. *An example of the coral reef mapping process for Heron Island, Australia from (top) scuba divers during the CORAL mission and (bottom) IG planning algorithm. (From left to right) RGB image; underlying entropy (uncertainty) map that guides the planning algorithms; mapping of coral, algae, and sand from each approach; ground truth map of coral, algae, and sand for reference. It is apparent that the IG planning algorithm outperforms the typical scuba diving approach, and that the CORAL mission and future coral reef mission would greatly benefit from these planning algorithms.*

Publications and References

Candela, Alberto, David R. Thompson, Eldar Z. Noe Dobrea, and David S. Wettergreen. “Planetary Robotic Exploration Driven by Science Hypotheses for Geologic Mapping.” IEEE International Conference on Intelligent Robots and Systems (IROS). Vancouver. September 2017.

Costanza R, d'Arge R, De Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'neill RV, Paruelo J (1997) The value of the world's ecosystem services and natural capital. Nature 387:253-260.