Do AUVs Dream of Electric Eels?

Dr. Jeffrey W. Kaeli, Research Engineer, Woods Hole Oceanographic Institution

266 Woods Hole Rd, Woods Hole, MA 02543 jkaeli@whoi.edu

Free-swimming autonomous underwater vehicles (AUVs) are unique from tethered remotely operated vehicles (ROVs) and human-occupied vehicles in the amount of data-driven feedback a human can provide during a mission. While free-space optical communications afford tether-equivalent data rates at relatively close ranges (Farr et al. 2010), most AUVs employ acoustic modems to maintain two-way communications with their operators while underway (Freitag et al. 2005). However, the low bandwidths and high latencies inherent in underwater acoustics prohibit the real-time transmission of data generated by imaging sensors such as cameras and side-scan sonars. This has profound implications with regard to the *meaning* of the data an AUV collects and the *trust* an operator has in the AUV's autonomy to react to data in the absence of direct human oversight.

Robots are fundamentally agnostic to the meaning of the data they collect, where meaning implies the qualitative ideas a human attaches to quantitative values. As more and more meaning is conveyed to the AUV, more and more trust can be built up by the operator. Thus, trust and meaning form a cyclic feedback loop that is throttled by the bandwidth limitations of underwater communication. Some of our recent work in marine autonomy has focused on co-robotic frameworks that address this concept in the context of real-time AUV operations. We briefly describe two frameworks for summary-based mapping and anomaly detection that reinforce operator trust by enabling a human to impart meaning upon data while it is still being collected by an AUV.

Summary-Based Mapping

Online summaries (Ghirdar and Dudek 2010) are a useful tool for data reduction in real time imaging pipelines, but their output lacks inherent meaning outside of a human's interpretation of the content. Compression algorithms now make transmitting imagery via acoustic modem during a mission a practical reality (Murphy and Singh 2010) but depend on a separate mechanism for selecting which images to transmit. Marrying these two strategies, the robot can first transmit a small number of images representing the classes that best represent the data collected thus far, allowing a human to attribute meaning to them. Combining class membership of non-summary images with navigational metadata enables the creation of simple maps whose indices correspond to each of the summary classes (Kaeli and Singh 2015). An example of this is shown in Figure 1 using 2,800 images collected by the SeaBED AUV in 2003 from the Stellwagen Marine Sanctuary.

Contrary to off-line algorithms that require all data to be collected prior to analysis, online algorithms maintain a current summary of the data at any point in the mission. While they offer less guarantees of stability or finding the optimal solution, they do provide a practical basis from which an AUV can begin to adaptively sample its environment. Even in the absence of operator feedback, pre-set classes can be stored to enable the AUV to search for certain substrates, ignore entire areas, or transmit maps without the need for compressing imagery. At the end of a mission, the operator possesses both an immediate high-level summary of the survey as well as the ability to selectively download the most meaningful parts of the dataset first. Enabling operators to begin interacting with data while a mission is underway makes the best use of both the AUV's resources and the operator's time while at sea.

Anomaly Detection

A robot can be trained to automatically detect meaningful objects of interest, but there are many types of objects that are difficult or impossible to train a robot to search for. In these cases, detecting anomalous regions that stand out from their surroundings can be useful for adaptively resurveying potential targets in opposed to relying on human post-mission analysis and a secondary deployment. We implement a two-tiered algorithm that first finds locally salient regions that differ from their surroundings, then clusters these regions to learn which are globally rare (Kaeli 2016). Applied to side-scan sonar imagery collected during the search for Air France flight 447, shown in Figure 2, this approach detected several anomalous regions that include the wreckage of the airplane.

One possible implementation is to resurvey a set number of anomalies per track line. This provides the operator with a richer data product while keeping the overall mission complexity low, simplifying tracking and improving operator trust in the autonomy. Background classes can be saved prior to deployment and subsequently ignored, or anomalies transmitted acoustically to allow an operator to decide whether or not a resurvey is merited. Even in the complete absence of human feedback, anomalies can serve as useful navigation landmarks, providing a stationary and unique reference for the AUV to reset its accumulated navigation error.

Conclusion

Many of the greatest advances in autonomy over the past few decades, from unmanned aerial drones to commercial airline autopilot systems, have borne the most fruit when autonomy is used to enhance operator perception rather than fully replace human oversight (Mindell 2015). However, this paradigm is particularly difficult in underwater robotics due to the extreme limitations of the communications channel, which slow not only the feedback loop of meaning and trust between vehicle and operator but also the time constant for development as well. One of the challenges facing developers of marine autonomy will be to design behaviors that, while they may inherently occur unpredictably, still prove tractable to human operators in the field. As a result, we advocate for the parallel development of co-robotic approaches that blur the traditional lines between AUVs and ROVs, hastening the cycles of meaning, trust, and development while creating smarter and more precise tools for understanding the oceans.

References

Farr, N., Bowen, A., Ware, J., Pontbriand, C., & Tivey, M. 2010. An integrated, underwater optical/acoustic communications system. In *Proceedings of MTS/IEEE OCEANS*

Freitag, L., Grund, M., Singh, S., Partan, J., Koski, P., and K. Ball. 2005. The WHOI micro-modem: An acoustic communications and navigation system for multiple platforms. In *Proceedings of MTS/IEEE OCEANS.*

Girdhar, Y., and G. Dudek. 2010, October. ONSUM: A system for generating online navigation summaries. In *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems*.

Kaeli, J. W. and H. Singh. 2015. Online data summaries for semantic mapping and anomaly detection with autonomous underwater vehicles. In *Proceedings of MTS/IEEE OCEANS*.

Kaeli, J. W. 2016. Real-time anomaly detection in side-scan sonar imagery for adaptive AUV missions. In *Proceedings of IEEE-OES Autonomous Underwater Vehicles*.

Mindell, D. A. 2015. *Our robots, ourselves: Robotics and the myths of autonomy*. Viking Adult.

Murphy, C., and H. Singh. 2010. Wavelet compression with set partitioning for low bandwidth telemetry from AUVs. In *Proceedings of the Fifth ACM International Workshop on Underwater Networks*.

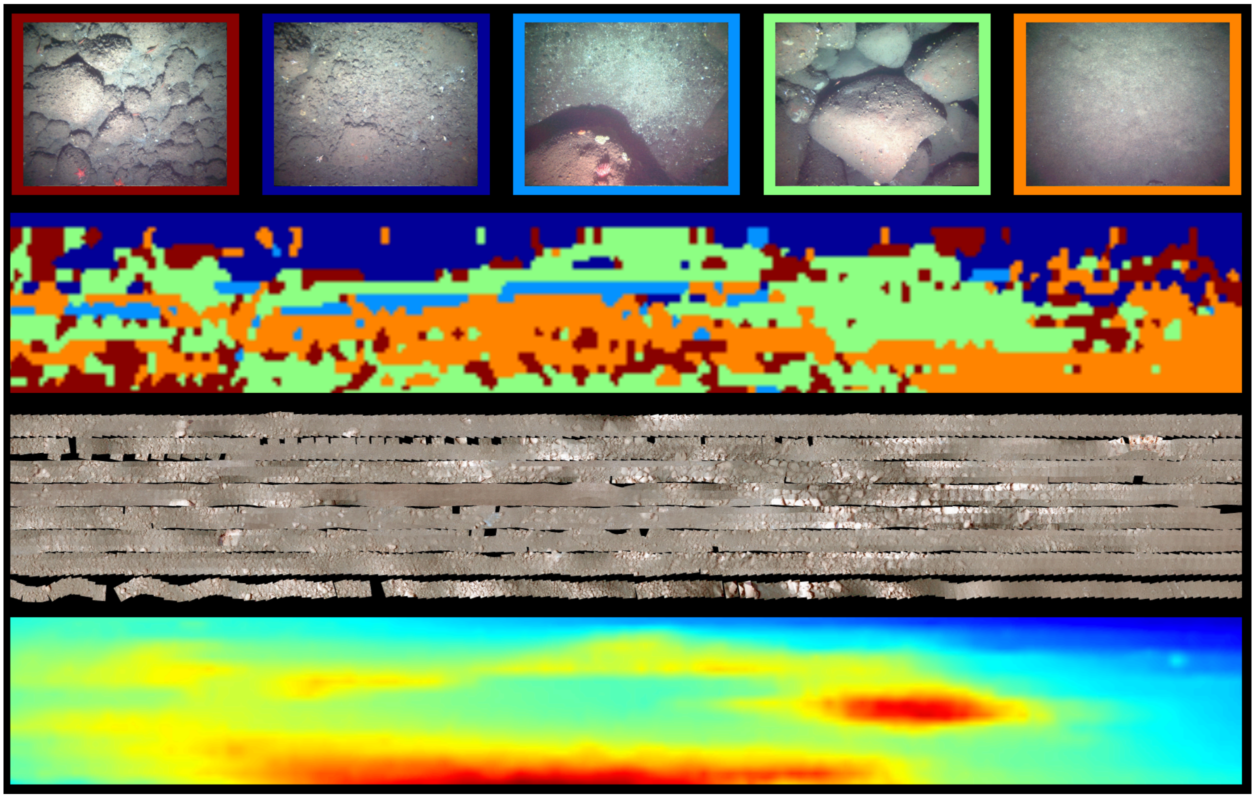

Figure 1. From to top to bottom: five images the algorithm selected that best summarize the dataset; summary-based map color coded by image class; photomosaic of the entire mission; bathymetry of the survey area. While the robot only understands the data in the context of "Class 1" or "Class 2," a human is able to attribute meaning such as "rocky" or "sandy" to the images and relate that meaning to the broader context of habitat or geomorphology.

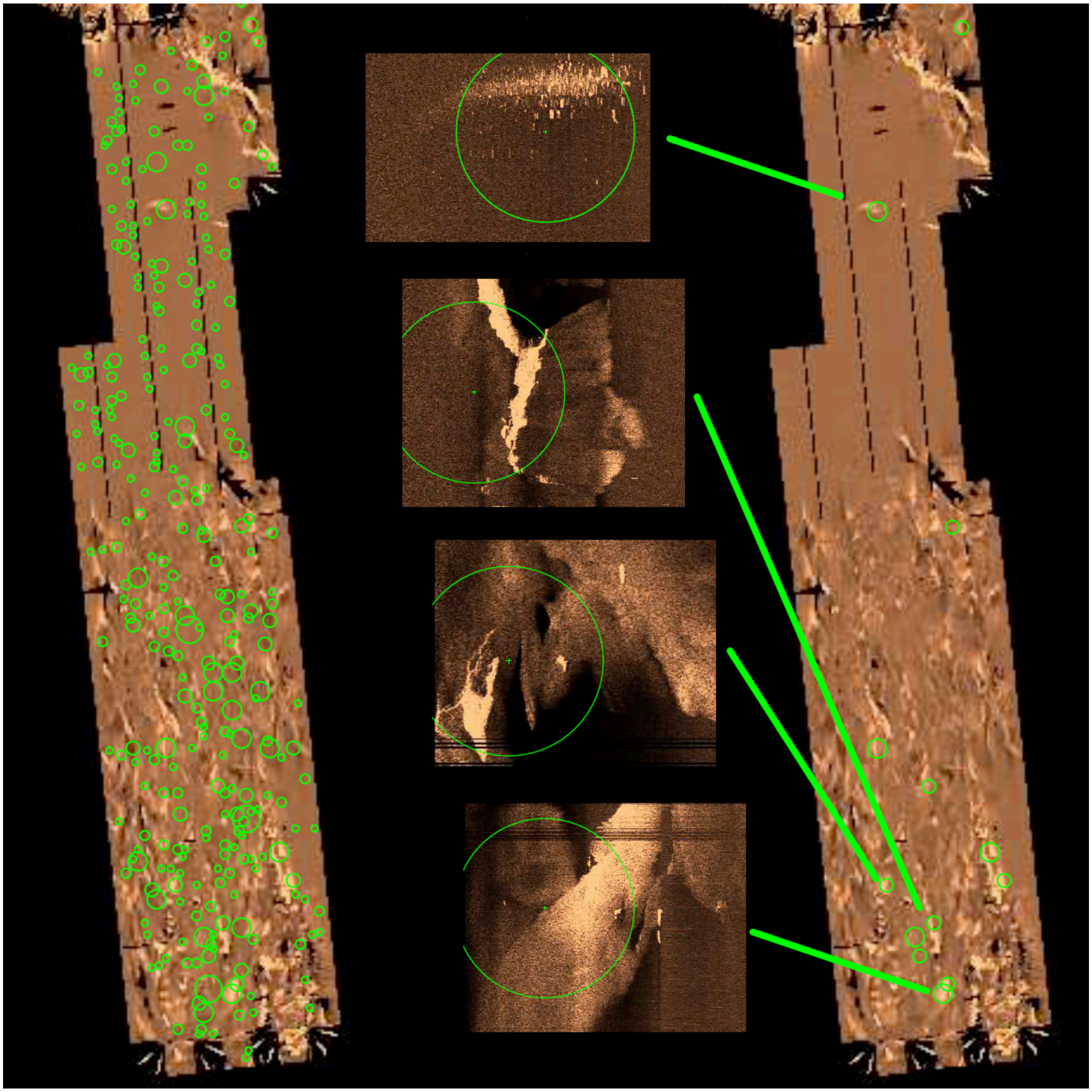

Figure 2. Locally anomalous regions detected in a side-scan sonar survey (*left*) are subsequently filtered to select only those that occur at a particular rarity and scale of interest (*right*). Sample detections (*center*) include the wreckage of Air France flight 447 (*top*) along with numerous geological formations.