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Development of High Resolution Sea Floor Mapping Tools and Techniques

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Development of high resolution sea floor mapping tools and techniques

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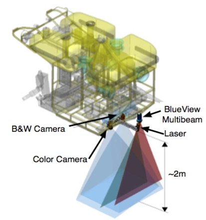
Overview

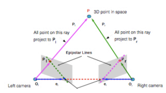
Addressing the persistent need for high resolution photographic and bathymetric sea floor maps for research areas in marine geology, biology, and archaeology, our lab uses high frequency multibeam sonars, stereo vision and structured light laser imaging techniques to create maps with centimeter level resolution. Data for this work was collected with the *Hercules* remotely operated vehicle (ROV) and with our newly developed Lagrangian imaging float.



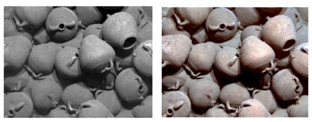
The ROV Hercules is deployed to survey deep sea sites. It is equipped with several mapping sensors including a multibeam sonar, stereo cameras, and a laser for structured light ranging.

A. Stereo

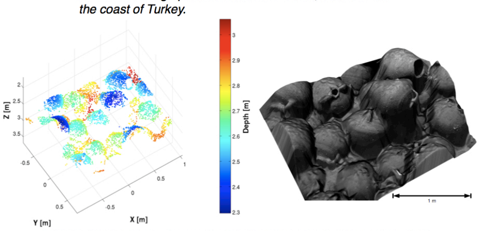
Stereo vision uses two view camera geometry (A.1) to reconstruct a 3D scene from paired overlapping images (A.2). Reconstructions are able to convey both shape and texture of the sea floor (A.3).



A.1 Two view geometry

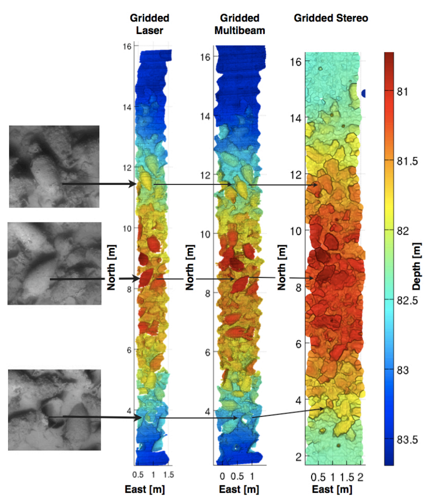


A.2 Stereo image pairs from Roman Wreck, Knidos F off the coast of Turkey.



A.3 The 3D points can be meshed to show the shape of the scene (left) and overlaid with an image to create a texture map (right).

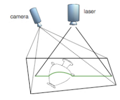
Reference: 2011 C. Roman, G. Inglis, J. I. Vaughn, S. Williams, O. Pizarro, A. Friedman and D. Steinberg, "Development of High-Resolution Underwater Mapping Techniques", in Bell, K.L.C., and S.A. Fuller, eds. 2011. New Frontiers in Ocean Exploration: The E/V Nautilus 2010 Field Season. Oceanography 24(1), supplement, 40 pp



This figure shows, respectively, structured light, multibeam, and stereo reconstructions of the same location. Each mapping technique has its own advantage: structured light gives the highest resolution and accuracy, multibeam sonar works regardless of water clarity, and stereo vision allows for easy texture mapping and visualization.

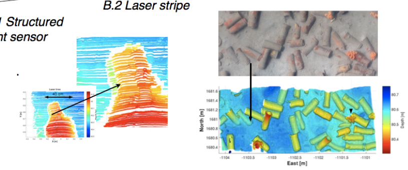
B. Laser

A structured light sensor consists of a sheet laser and a camera arranged in a known (calibrated) geometry (B.1). The 3D scene structure can be calculated using triangulation from the observed position of the laser stripe in the image. The laser line is automatically extracted from images (B.2) and combined with vehicle navigation data to produce fine scale bathymetry maps (B.3). This technique is able to achieve sub centimeter resolution and convey fine details of objects or the sea floor.



B.1 Structured light sensor

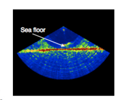
B.2 Laser stripe



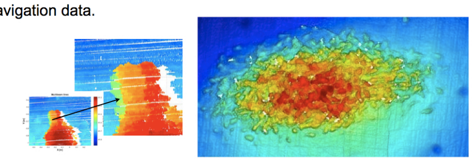
B.3 Each image can be triangulated into one strip of range data (left). These strips are aligned using vehicle position data into complete maps (right).

C. Multibeam

Multibeam sonars use an array of hydrophones to make both range and angle measurements to resolve the heights along a slice of the sea floor (C.1). At frequencies greater than 1.3 MHz, centimeter level resolution is possible for ranges between 10 and 30 meters. Accurate bathymetry maps are made by combining sonar data with the vehicle navigation (C.2). We currently use an automated registration technique that uses the multibeam data to reduce errors in the navigation data.



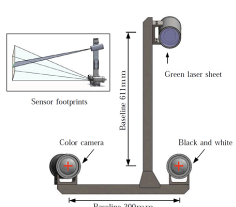
C.1 Multibeam Sonar Ping



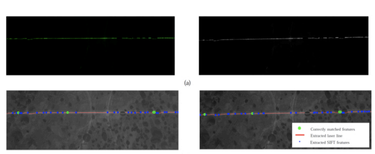
C.2 Individual pings aligned using navigation data (left) to make a full map (right).

Laser Calibration

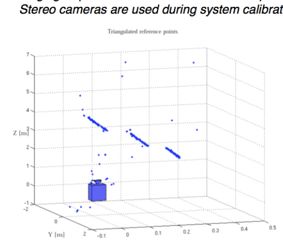
Producing accurate 3D estimates with the structured light system requires precise knowledge of the relative camera and laser geometry (D.1). While the concept is well understood, the standard calibration techniques which require the exact position of reference points illuminated by the laser plane are difficult to achieve underwater. We developed a method for calibrating an underwater structured light sensor based on localizing 3D reference points using stereo cameras (D.2, D.3). This method can be used over natural terrain, allowing for in-situ validation and re-calibration of the structured light system (D.4).



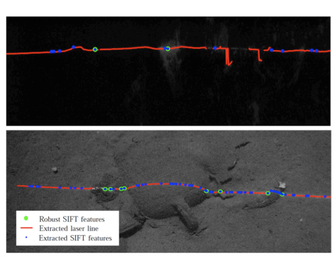
D.1: CAD model of the stereo/structured light system. Stereo vision requires two cameras & structured light ranging requires one camera and one laser plane. Stereo cameras are used during system calibration.



D.2: (a) Stereo image pair, necessary to reconstruct 3d scene structure of the laser line. (b) Feature points and matches along the laser line for a stereo pair: Blue points are interesting features, green points are features successfully matched with a corresponding feature in the conjugate image. Feature matches can be triangulated to obtain a 3d point position.



D.3: Triangulated reference points help define the laser plane during calibration. The points in this figure represent calibration scans at three ranges.



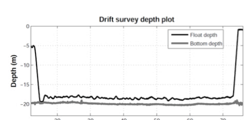
D.4: Two survey images representing successful matching over various terrain types: Extracted laser line overlay (red), extracted feature points (blue) and robust feature points (green). Kolumbo Volcano, Santorini, Greece (top) Byzantine shipwreck, Turkey (bottom)

Reference: 2011 G. Inglis, Smart, C. Roman, C. "In-situ calibration of a structured light system for underwater mapping" IEEE IROS 2011. Submitted.

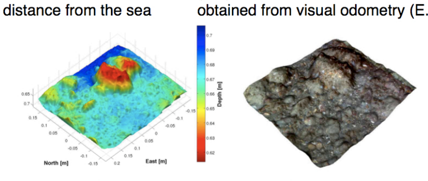
Lagrangian Float

E.1: Lagrangian float & camera system.

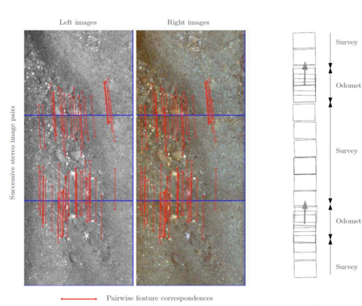
Lagrangian floats have long served as freely drifting oceanographic instrument platforms with low operating costs and minimal supervision requirements (E.1). While often used to profile vertically and collect water column data, our lab has designed a float to drift with the current and maintain a constant distance from the sea floor (E.2). The ability for the float to maintain a constant one meter altitude allows a pair of cameras to image the sea floor in a repeatable manner. Data products from the stereo images include 3D scene reconstructions (E.3), flat mosaics (E.5) and bottom current measurements obtained from visual odometry (E.4) .



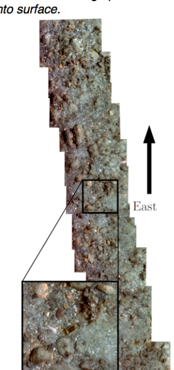
E.2: Float depth over time. The survey mission is programmed to maintain a low constant float altitude for imaging.



E.3: (a)Micro-bathymetry reconstruction from stereo image pair. (b)Bathymetry with images projected onto surface.



E.4: (a) Image correspondence points between overlapping stereo pairs, used to reconstruct the speed and direction of the float with visual odometry techniques. (b) Illustration of the alternating survey-odometry timing sequence. Low overlap images save power while periodic bursts of images allows drift track reconstruction.



E.5: 12 image mosaic from a float survey off Scarborough Beach, RI.

Reference: 2011 C. Roman, G. Inglis and B. McGilvray, "Lagrangian floats as sea floor imaging platforms" Submitted - Continental Shelf Research

Acknowledgements: Institute for Exploration (IFE), Ocean Exploration Trust (OET), National Science Foundation (NSF) grant number - 1031137, Office of Naval Research (ONR)