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Surface metrology and 3-D imaging with laser line scanners

by Donna M Kocak and Frank M Caimi[1], Harbor Branch Oceanographic Institution, USA

A fundamental aspect of geological mapping, both above and below the ocean surface, is the documentation of the orientation of various planes and lines in space. Examples of planar structures observed along mid-ocean spreading centres, for instance, are sedimentary bedding, lava flow tops, dike margins, igneous layering, metamorphic foliations, joints and faults. Land geologists determine the orientation of similar outcrop-scale features with various types of hand-held compasses and inclinometers, like the Brunton Compass used widely in North America. However, this type of instrument is not appropriate for use on the seafloor and different approaches are required to obtain orientation data.

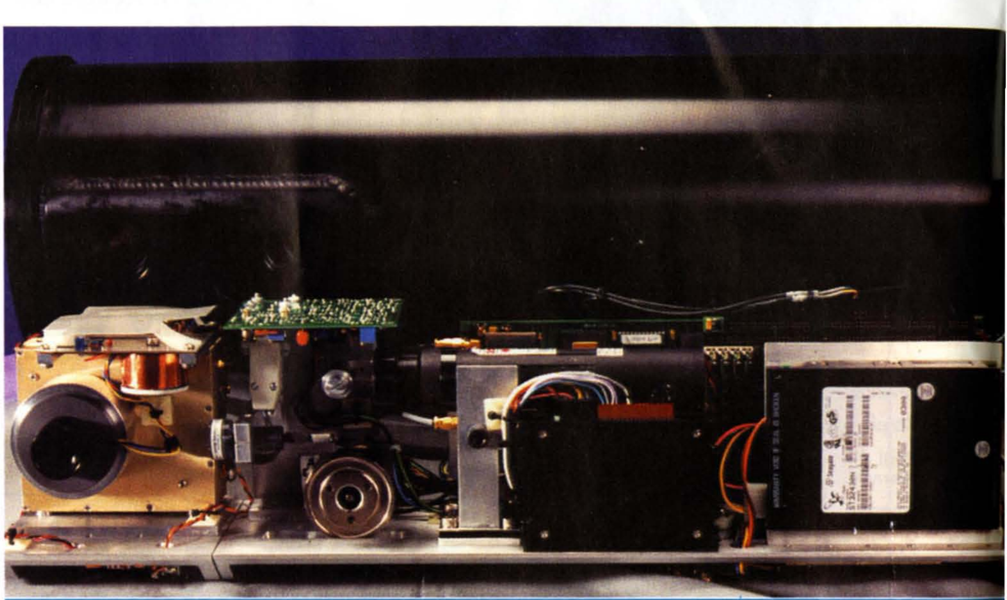

Fig 1: Laser line scanner developed for USM.

A LASER IMAGING system currently being developed by engineers at Harbor Branch Oceanographic Institution (HBOI), under NSF and Duke University sponsorship, affords a method of collecting orientation data. The system produces three-dimensional maps of all visible surfaces within a volumetric region using a low power laser scanner and proprietary detector. The resulting 3-D map co-ordinates, combined with the measured roll and pitch angles of the instrument, are used to accurately determine orientation of the scanned geologically relevant planes and lines on seafloor outcrops. Unlike other techniques currently in use, this instrument does not need to be carefully positioned or placed on the rock surface and is not affected by magnetic fields. Furthermore, due to the high scan rate, the instrument need not be perfectly stationary while scanning. During a single seafloor traverse thousands of measurements can potentially be made.

The system uses a triangulation measurement technique to sample a reflective, two-dimensional contour within a region of space that is viewed simultaneously by a position sensitive detector. A laser is scanned continuously throughout the volume in a line-by-line fashion to create a continuous reflection map at the detector

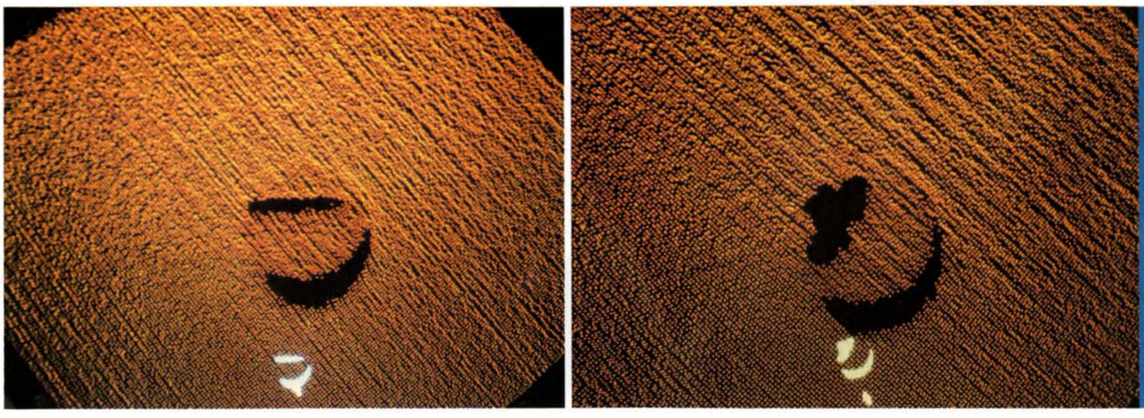

Fig 2: 200 x 200 pixel range maps of (a) 1cm diameter slot-head screw and (b) 1cm diameter Phillips-head screw recorded in air at a nominal range of 1 metre with 1mm depth resolution (NCEL).

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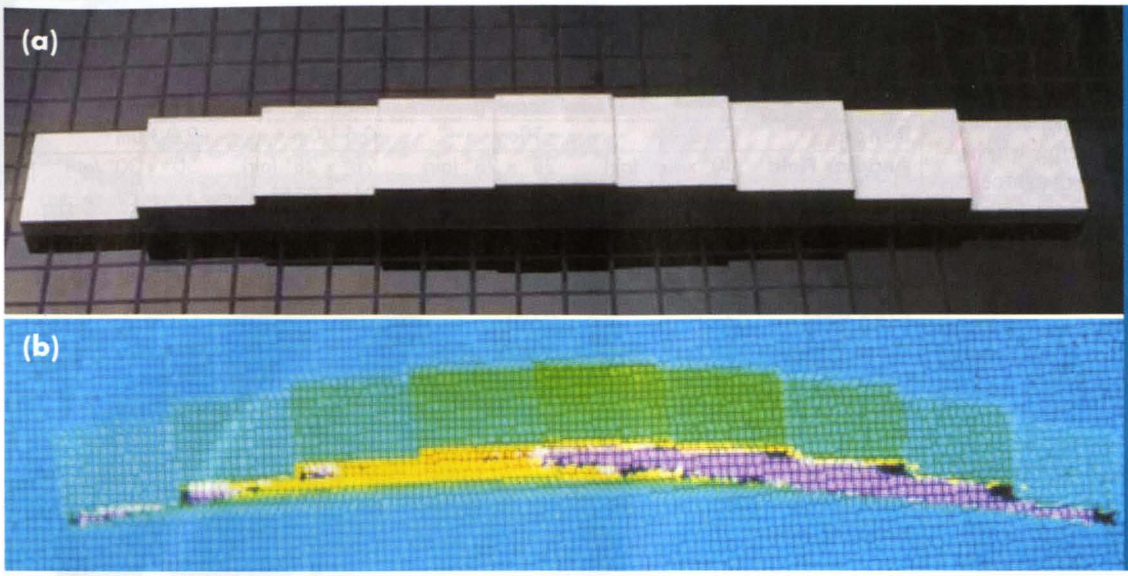


***Fig 3:* Step wedge photograph (a) and 400 x 400 pixel resolution scanned image (b) with colour gradation denoting changes in range (NCEL). Note that the topmost step is 1mm in height from next step.**

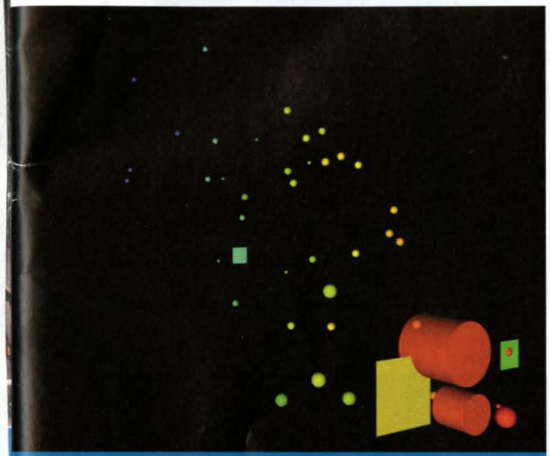


***Fig 6:* Render of segmented marine snow range map (USM).**

***Fig 4:* 400 x 400 pixel range maps of dome and step wedge test objects recorded in clear water at a nominal range of 1 metre (NCEL).**

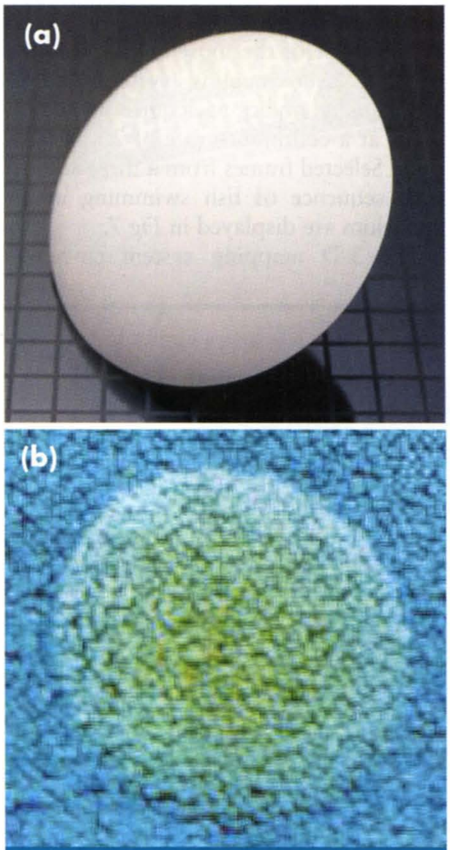
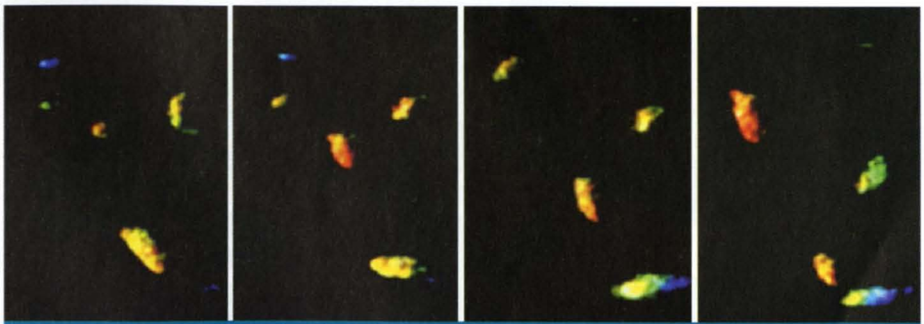


***Fig 5:* Dome photograph (a) and 400 x 400 pixel scanned image (b) with colour gradation denoting changes in range (NCEL).**

surface. The map contains information from which a unique range estimate can be obtained for each point in the scan. It is only necessary to know the pre-calibrated scan angles, separation distance (constant) between the laser and detector and detected position in the reflectance map for each point. Pairs of co-ordinates (Øx, Øz) are computed from the detected signal which, in turn, can be converted to position (x, y, z) data for the entire volume.

Three laser line scanners have been developed by HBOI for specialised applications. The design specifications for each are shown in *Table 1*. The first system, designed for the Naval Civil Engineering Laboratory (NCEL), is used for robotic inspection and operates in multi-resolution modes of 134 x 134, 200 x 200, 400 x 400 and 800 x 800 pixels. This system demonstrated an accuracy of 1mm at a 1m distance.

Another system, developed for the University of Southern Mississippi (USM) Department of Marine Science, shown in *Fig 1*, was designed to view marine snow aggregates. This system has been deployed on a Benthos Open Frame ROV in Antarctica and on the Johnson Sea-Link submersible in the Bahamas.



(a) t = 0.35 s (b) t = 1.15 s (c) t = 1.75 s (d) t = 2.75 s

***Fig 7:* 200 x 200 pixel resolution range maps of fish in an aquarium taken from a 3 second sequence where the first image is at time t = 0 seconds (HBOI).**

Resolution of the collected images is approximately 1mm in each of the (x, y, z) dimensions at standoff distances less than 10cm. The image acquisition rate of 20 complete 3-D surface maps per second was chosen to eliminate blurring of the moving particles. A similar instrument designed for HBOI use captures sequential frames for motion studies at a nominal standoff distance of 0.5m. Example images from each of these systems are shown in *Figs 2-7*. The images shown in *Fig 2* illustrate a one part in 1,000 range resolution at a nominal standoff distance of 1m. This resolution was tested using the step wedge depicted in *Figs 3 & 4*. Pseudocolour in the displayed images illustrates range gradations as shown in *Fig 5*. Scans of marine snow aggregates have been analysed using a post-processing algorithm to illustrate particle size, shape and volume as shown in *Fig 6*. Perhaps one of the most unique features of this laser imaging system (USM, HBOI) is its ability to acquire full frame scans at a continuous rate of 20 per second. Selected frames from a three-second scan sequence of fish swimming in an aquarium are displayed in *Fig 7*.

	NCEL	**USM**	**HBOI**	**Duke (preliminary)**
Application	ROV inspection	Biological mapping	Biological mapping	Geological mapping
Range	0.5-2.0m	<10cm	0.5-1.0m	2.0-3.0m
Angular Field	40° x 40° (air) 30° x 30° (water)	28° x 28° (air) 21° x 21° (water)	28° x 28° (air) 21° x 21° (water)	30° x 30° (air) 22° x 22° (water)
Accuracy	1 in 1000	1 in 200	1 in 200	1 in 100
Pixel Resolution	134^2, 200^2, 400^2, 800^2	200^2	200^2	100^2
Scan Rate	<4s	0.05s	0.05s	0.10s
Laser Power	150mW	10mW	10mW	75mW
Laser	532nm	670nm	670nm	532nm
Power Source	115 VAC	150±50, 28±5 VDC	150±50, 28±5 VDC	120VDC
Depth Rating	914m (3,000ft)	914m (3,000ft)	914m (3,000ft)	4,500m (14,764ft)
Viewpoints	Acrylic, dome	Acrylic, flat	Acrylic flat	Acrylic flat
Housing size	57in.L x 9in. OD	28in.L x 8in.OD	28in.L x 8in.OD	12in. & 20in.L x9in. OD
Housing Material	Anodised AL	Anodised AL	Anodised AL	Titanium

***Table 1:* Design specifications for each of the laser line scanners developed by HBOI.**

The 3-D mapping system currently being developed for Duke University will be used to make quantitative measurements relevant to studies of slope morphology, sedimentology, hydrothermal vents, biology, structural geology and rock magnetism. The preliminary design will produce image maps of 100 x 100

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systems transmitted from the support vessel, seabed beacons or some other source.

- Preferably capable of utilising position updates from GPS when on the sea surface.
- Doppler velocity log capable of operations over a variety of seabed soils.
- Dead reckoning during short periods of loss of navigation data.
- Collision avoidance logic.

Flying height

- Survey AUVs must be capable of operating at a variety of flying heights above the seabed.
- The minimum flying height will be controlled by requirements of the 500kHz side scan sonar.
- Capable of maintaining a fixed survey altitude over a rugged seabed terrain or maintaining a constant depth as the terrain changes.

Data supervision and QC

To ensure integrity of acquired data and mission alteration.

- Variations to the AUV mission shall be possible from the support vessel.
- As a minimum, the survey AUV shall be capable of self-checking and cessation of operations if systems are non operational.
- The AUV shall preferably transmit status flags to the support vessel. Sub-sampled raw data is the preferred status flag.
- To ensure data integrity, it is preferred that a significant amount of sub-sampled raw data is transmitted to the support vessel.

Data logging/storage

- Compatible with the endurance of the survey AUV when operating all survey sensors at their maximum sample rate.
- Data logging frequency compatible with the survey sensor.

Time synchronisation

- All sensors including navigation shall be precisely time synchronised at all times.

Integrated packages

- Payload sensors shall not interfere.
- Simultaneous operation of multiple survey AUVs is preferred.
- AUVs shall be capable of operations in environments with acoustic noise (coherent or random).

'Nice to Have' (not essential)

- Capability to add additional sensors.
- Visual capability (video/stills).
- Magnetometer.
- Hydrophone for use with other acoustic sources.
- Capability to dock into a 'garage' and download data/recharge.

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pixels at a rate of 0.1 second. The system incorporates a single-board Pentium 233MMX CPU, 60 MHz TMS320C4x DSP processor, analog/digital I/O board, scanner driver board, and communications interface for hardware control. Communication is provided to a laptop control and display unit via RS-232 data link that can be connected through an umbilical. A 100 Mbit ethernet interface is also provided for rapid transfer of images. Designed for a 4,500m operational depth, two titanium housings (12in. L x 9in. OD and 20in. L x 9in. OD), each with a flat acrylic viewport, embody the scanning and detector assemblies, respectively. A penetrator provides a keyboard and monitor interface that allows for benchtop monitoring and control of the downside prior to being deployed. Power requirements for the system are less than 200 watts from a single source of 120 VDC. Thus, with its modular design and deep-ocean rating, the system can be mounted on virtually any underwater platform. Initial deployment is expected on Woods Hole's *Alvin* submersible in the year 2000.