DSV Alvin
Multibeam Mapping
Primer/Cooker

Version 1.15
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SJM

INTRODUCTION

Deep Submergence Vehicle *Alvin* supports research requiring multibeam acoustics through use of two commercial sensor systems. *Alvin's* primary multibeam system, the Reson Seabat 7125, operates in modes of up to 512 beams in a 128 degree fan at a frequency of 400 kHz. It is regarded as a premier bathymetric sonar system, and additionally can be applied to a variety of other types of scientific investigation of seabottom and water column. The Imagenex 881 is a mechanically scanning altimeter operating at 675 kHz and is regarded as a backup system for less precise bathymetry work.

Science parties who wish to collect multibeam information should have started working toward that goal with the *Alvin* team in the pre-cruise planning stage. At-sea arrangement of dive itineraries will continue with the Expedition Leader, who will conduct the effort to install and prepare a multibeam system on the submersible. Prior to a dive, the science party is responsible for laying out a survey for the approval of the Expedition Leader and that dive's pilot.

Among the decisions to be made is the choice of sonar system. The Seabat 7125 system draws considerable electrical power at about 150 watts and, when working throughout the duration of a dive, will shorten dive time length by perhaps a half hour. It requires a significant portion of the discretionary weight budget at about 75 pounds and will offset about 30% of weight available for samples. The Imagenex draws about 20 watts and offsets less than ten pounds of the discretionary weight budget. On balance, we expect that the superior measurement capabilities of the Reson system will make it the user's primary choice. For that reason, the focus of this document is on use of the Reson Seabat 7125 system. For a more detailed description of Imagenex 881 operation and characteristics please see the paper by Ferrini et al, which is listed in the Resources section.

Best use of the Seabat 7125 is to accompany it with a person devoted to monitoring its function and logging navigational and topographical events during a dedicated survey. Ultimately the quality of a bathymetric map is determined by the navigation information that accompanies the sonar data. To accurately tie a measured range to the correct footprint on the sea floor requires precise and high resolution timing, positioning, attitude, and heading. Success of the resulting bathymetric map is much more certain when history has available the external checks from an archived timeline.

A survey plan should be developed with the expedition leader prior to the dive. As a conservative general rule, survey designers should plan on distances between adjacent track lines of twice the altitude minus twenty percent (1.6 * altitude) in order to reliably achieve overlap between swaths. If time is short, some increase in swatch spacing is possible. More overlap is better, but this geometry is based on use of the multibeam fan "sweet spot" (the center 90^{0} of the multibeam arc) and there is some extra overlap built in. The survey plan should also include bias measurement spins and a patch test, and one or more cross lines should be considered. The

SM2000 sonar planning information found on the web page at *http://www.whoi.edu/page.do?pid=11303* will provide some guidance regarding the relation between swath spacing, altitude, and survey time.

The primary navigational instrument used during the survey is called a Doppler Velocity Log, or DVL. DVL systems offer high sample rate and resolution, but are altitude-limited. This forces flight at a conservative height above the sea floor so as not to lose DVL bottom-lock during a survey. The limitation is a function of DVL operating frequency: a 300kHz system can find bottom lock at an altitude of up to about 200 meters; a 600 kHz can find bottom lock at an altitude of up to about 110 meters; a 1200 kHz DVL can find bottom lock at an altitude of up to about 25 meters. *Alvin* currently operates using a 1200 kHz DVL and in 2010 will add a 600 kHz DVL to its inventory. This is relevant to survey design in that there's a direct relation between bottom coverage and sonar altitude: higher flight means greater expanse of the multibeam "fan", or swath width, and the spacing between survey tracklines can be increased. There is a corresponding increase in the size of each beam's seafloor footprint, resulting in less resolution, and the survey designer will have to weigh these factors.

DURING THE DIVE

Later in this document an example user in-survey checklist. For best results, this checklist should be exercised and annotated by the responsible operator prior to and during a survey. Additionally, the observer should keep a log throughout the dive and make this log a permanent part of the survey record after the dive by submitting a plain text file to *Atlantis'* SSSG technicians, who create the permanent cruise data packages. Please see the example of an event log file that's included later in this document.

Because *Alvin's* hull penetrators do not pass the high frequency data signals between sonar heads and the Reson control computer, the computer is external to the personnel sphere in a pressure housing. A Reson client program runs on the notebook, providing much of the look and feel of the main Reson control software. Experienced users will notice that use of the client results in some loss of features, most of them unimportant. More importantly, the required bandwidth between main program and client sometimes exceeds availability. On these occasions most control and display function is lost and the user is compelled to remotely restart the main software. Additionally, there's no capability to make screen recordings.

The DSV *Alvin* project has earned a peerless record as a platform for taking scientists to the ocean floor for close observation. The vehicle's design has been prioritized for the safety of its passengers and for the gathering of visual and physical samples while at depth. Its usual mode of operation is to bring its passengers to within a few meters of the bottom and to hover there while samples are gathered, measurements with probing sensors are made, and visual recordings are captured. Unfortunately, these degrade multibeam survey measurements. The placement of the Seabat transmit and receive heads low on the *Alvin* frame (lower than basket level) means that data from the system is generally unusable whenever the sea floor is in visual range. *Alvin's* design and usual mode of operation also directly conflict with the collection of best navigation data in the following ways:

1. *Alvin's* position is primarily determined from time integration of measurements made by a Doppler Velocity Log (DVL) dead reckoning sensor. This type of system is susceptible to drift when used close to the sea floor, adding uncertainty to positioning. In highly sedimented environments Alvin's thrusters can stir flocculant material that interferes with DVL lock on the stationary bottom, further increasing DVL uncertainty. In rocky environments the irregularity of the reflections increases accumulated errors and thereby adds to positional uncertainty.

2. *Alvin's* ultimate escape feature uses a single point mount of the personnel sphere to the vehicle frame. The Reson's transmit and receive heads are mounted to *Alvin's* frame while attitude and heading sensors are mounted within the personnel sphere. The loose physical connection between sphere and frame means significant uncertainties in measurements of attitude and heading of the sonar heads.

The best way to counter these issues is to gather as much information as possible during the performance of the survey. That way the person attending to post-processing can account for as many variables as possible. The level of detail in the log should be high enough support reconstruction of the survey in post-processing by a person with sparse knowledge of that dive's itinerary or of Alvin's operating procedures.

For post-processing success, a science observer should make consistent effort to take the following throughout the survey:

1. Periodic **screengrabs of DVLNav track history** at zoom levels that show an informative context. That is, zoomed in enough to show detail of track history but zoomed out enough to show the track placement within area topography and targets layout. Screengrabs showing changes in vehicle state, e.g., Doppler lock status are also useful. *Alvin's* DVLNav is set up to autosave a screengrab every 15 minutes, and does so with no regard to displayed content and context. Don't depend solely on these autograbs to provide useful information to a post-processor. An extra well-framed screengrab or two in those 15 minutes will be valuable to post-processing personnel. Note that *Alvin's* pilot performs the screengrab, not an observer.

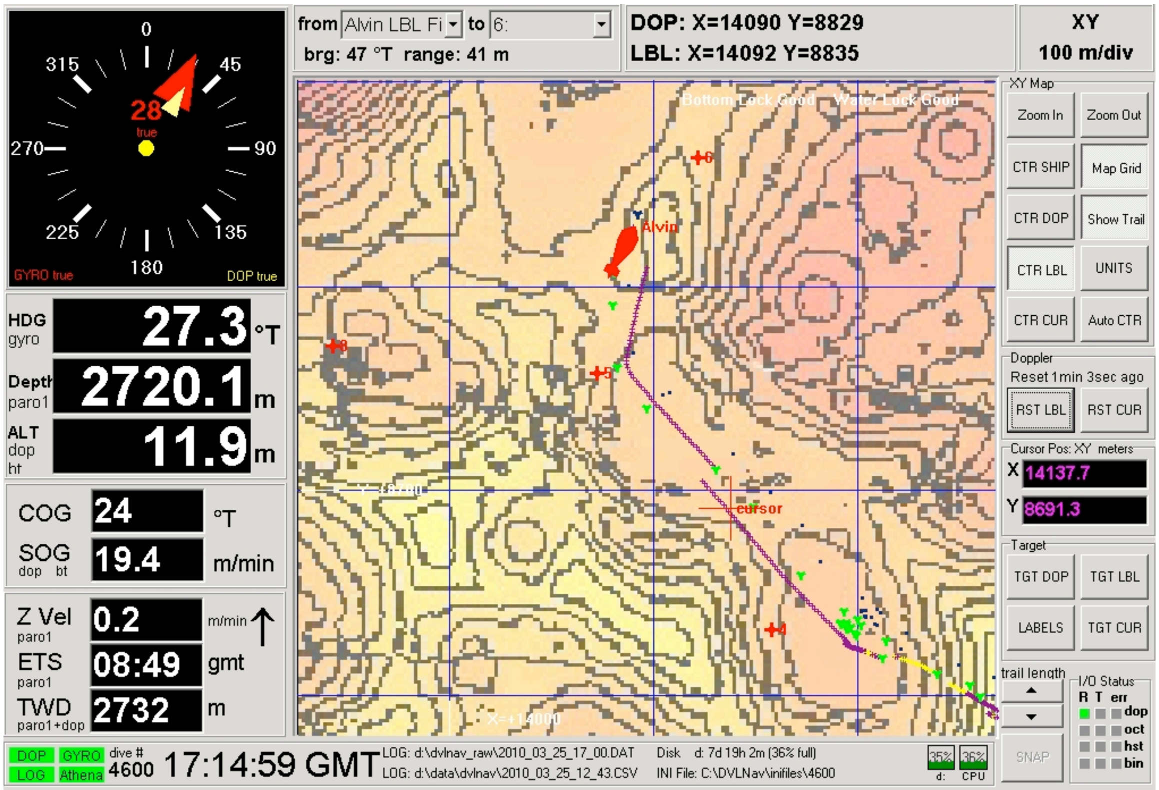

Figure 1: This screenshot provides informative context, showing the vehicle and its well-scaled track on top of a topographical underlay. A DVL reset event is evident.

2. **Survey notes**, with time and event description. Please see the event log example in the main body of this document.

Notable events include:

Start/end times of survey lines.

Turn direction and vehicle heading.

Changes in Alvin altitude of more than 5 meters.

Loss of DVL bottom lock.

Other important navigation events, e.g., extended loss of LBL tracking.

Activities that could result in shift of roll and pitch of the personnel sphere, e.g., exchange of body locations. This will change the relation between the in-sphere roll/pitch/heading sensors and the sonar head.

Visual or acoustic observations of topographical features.

Patch Test

This term refers to a procedure that is designed to isolate static system biases, e.g., inaccurate measurement of INS alignment, from measurement variables. Provided with a short set of measurements the data processor can process them to estimate these biases. We recommend the following on the most level nearby seabottom:

1. Full vehicle spin, both directions, keeping the sub over the same spot, at an altitude similar to that to be used in the survey. Spin speed should be approximately 3° per second.
2. Straight line out and then retracing it back, with the vehicle looking forward in each direction. Perform this at the survey altitude, and if time permits, and 0.5 * survey altitude and 0.25 * altitude. Line length should be about 50 meters, or about 3 minutes at 0.5 knots.

For these measurements to be useful to the data processor, log the events in detail.

Example survey event log file:

In the following example time resolution is to the minute. This is usually sufficient for most events, but recording events to the second IS encouraged. ***Seconds resolution for patch test events is required;*** *this test requires little time, and minor uncertainties can have a dramatic effect on post-processing.*

Date: 1/1/2020
Dive: 6000
Cruise: AT18-35
Logger: Jane Doe

All times GMT

Abbreviations:
heading=h
meters=m
altitude=alt
length=l
seconds=s
speed/velocity = v
X=eastings position
Y=northings position

Survey design: 9 lines SW<->NE, l=510m, track spacing 100m, alt 60m, patch test, two cross lines.

135410 Start bias spin to starboard, alt 40m, h=140
135620 end starboard spin, h=150
135635 start spin to port, alt 43m, h=140
135830 end port spin
140005 Start patch test l=30m, alt 60m, h=180, v=0.25 m/s
140155 reverse track, alt=60m, h=000
140455 original track new height, alt=30m, h=180, v=0.25 m/s
140703 reverse track, alt=30m, h=000

140910 end patch test
141145 start survey line 1, alt=60m, h=045, l=510m, X=11800,
Y=4532, spd 0.25 m/s
1425 lost DVL bottom lock over knife edge feature, X=12005, Y=4737.
1426 regained DVL bottom lock
1453 end line 1
1459 start of line 2, X=xxxxx, Y=yyyyy, h=225, etc
.
1614 pass waypoint 4, new heading = hhh
.
1852 end line 9, end of main survey, move to start of first crossline
1902 start crossline 1,alt=60m, h=135, X=, Y=
.
.
2015 end crossline 2, end of multibeam measurements.

Other significant events:
Observed in real-time multibeam a ravine feature SE of track line 4 near X=____, Y=____, time 1420-1422.

Passed marker #234 @ 1558, this dive X-Y was 4 meters west/ 2 meters south of position recorded when marker was placed, cruise AT17-13_XXXXXX18.

RESOURCES
Reson Seabat 7125 Operator's Manual and Release Notes.

POST-PROCESSING

NAVIGATION
The first and most difficult step in making a map is to produce synoptic timelines of the six requisite navigation parameters: longitude, latitude, depth, roll, pitch, and heading. These should be at a several per second rate, with positional precision of less than a meter and accurate roll, pitch, and heading with resolution of 0.01 degrees.

Recall that Alvin's attitude and heading sensors are contained within its sphere. It is likely that every turn of the submersible during the survey will force a measurable change in how Alvin's personnel sphere rides on the vessel frame. It is expected that this relation will be fairly stable between turns. Therefore, biases in attitude from individual track lines should be determined individually and removed from the navigation for each track line, then reassembled for a complete navigation history.

The primary source for this information will come from the high data rate log files produced by the DVLNav program that was running on Alvin during the dive. These files will have names of form *YYYY_MM_DD_HH_MM.DAT.zip*. They are large ASCII files that have been compressed to save disk space, and must be uncompressed with an unzipping utility. It is also likely that one of the DVLNav *INI.M files (name of form *YYYY_MM_DD_HH_MM*_DVLNAV_INI.M) will be required, particularly if using National Deep Submergence Facility-developed software to process the files. The _INI.M files contain information about the placement of sensors aboard Alvin.

DVLNav log files will be offloaded from *Alvin* post-dive by an *R.V. Atlantis* SSSG technician. During the cruise they can be found on the ship's web site (www.atlantis.whoi.edu) under the links "All Data for this Cruise", then "alvin", then "dvlnav_raw". After the cruise they will be found within the data package given to the cruise Chief Scientist. This same data package will be archived at the Data Library of the Woods Hole Oceanographic Institution. Once per second DVLNav log files in comma-separated value (csv) format will also be found in the data package. These can be used for quick analysis of a dive's navigation history but are unsuitable for producing the navigation data that will be the basis for a multibeam bathymetry map.

This dead reckoned track history can be augmented with lower rate reference frame (georeferenced) information from one of the following sources, which will vary by cruise and even dive:

1. R.V. Atlantis-based Ultra Short BaseLine (USBL)
   or
2. Transponder-based Long BaseLine, (LBL) also recorded in Alvin's DVLNav logs.
   and
3. Transponder-based LBL recorded by a second instance of DVLNav running aboard Atlantis.

At the current time either USBL or LBL will be available, but not both. Augmentation is accomplished by various methods, depending on which georeferenced navigation source is used.

MULTIBEAM RANGES

The raw files produced by Alvin's Seabat 7125 system are a binary format that's compatible with several software packages, including the NSF-supported open source package called MB-system.

Typically recorded are:

1. Reson record type 7000: sonar settings
2. Reson record type 7004: beam geometry
3. Reson record type 7006: bathymetric (range by beam) measurements

Less often but commonly recorded is:

4. Reson record type 7007: backscatter (sidescan) measurements.

Other record types can be recorded, resource permitting, by prearrangement with the *Alvin* Expedition Leader. Other record types of likely interest are 7018 (magnitude and phase data) or 7028 (Snippets). Both are **very** demanding of resources and should be used **carefully**.

POST-PROCESSING FLOW LIST

This will differ depending on whether the Reson Seabat 7125 or the Imagenex 837 was selected. The Seabat 7125 can be processed using community supported MB-system, or commercial such as *Caris*. For the Imagenex 837 NDSF can make available a homegrown Matlab-based package and cookbook; MB-system may also support processing of its data, but this has not been confirmed. The typical MB-system steps are as follows:

1. Merge previously processed navigation history (in .ppl format) with raw Reson files (in .s7k format) using 'mb7kpreprocess'.
2. Separate the survey segments into logical sections, e.g., patch test, main, crosslines, using 'mbcopy'.
3. Remove bad sonar pings and beams using utilities like 'mbedit' and 'mbclean'.*Note: NDSF uses a customized version of mbclean that reduces interactive ping editing. Contact NDSFDataMgr@whoi.edu.*
4. Apply the cleaning criteria using 'mbprocess'
5. Apply further refinements using bias information determined from patch test findings, from applying 'mbnavadjust' to comparisons between crosslines and main survey lines, or from processing trial and observation. Repeat earlier steps. Repeat again.
6. Use MB-system gridding and plotting utilities to produce a map. Diagnose problems. Repeat flowchart.

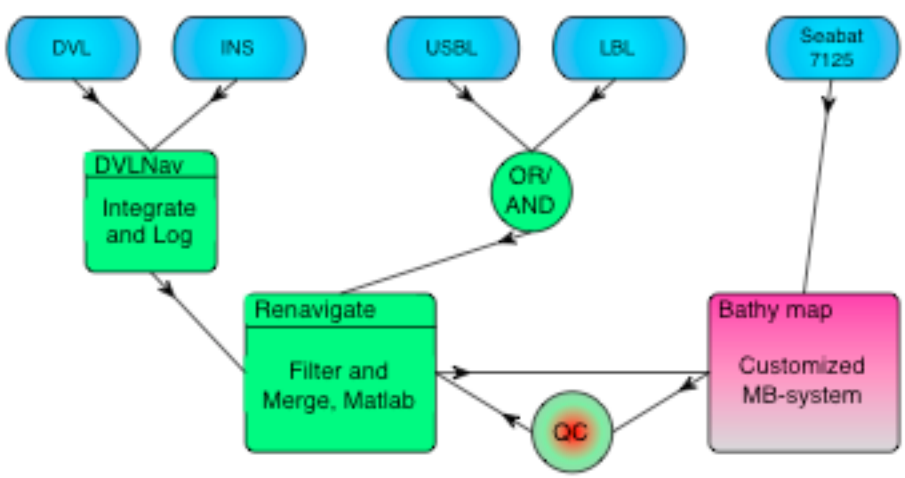

Figure 2: Generalized post-processing flowchart.

MB-system produces a number of intermediate files during processing, including "fast bathymetry" format (fbt) files. The Pro version of the software package called *Fledermaus* ingests fbt format files, and users may wish to use the processing (CUBE) and visualization features of *Fledermaus* as part of their processing workflow.

RESOURCES

DVLNAV home page and formats document: *http://robotics.me.jhu.edu/dscl/dvlnav/*
Reson 7K Data Format Definition document.
Sonardyne Ranger system manual.
MB-system cookbook, mail list, web sites, *http://www.mbari.org/data/mbsystem/*
MB-system fbt format definition, http://www.ldeo.columbia.edu/res/pi/MB-System/batheditintegration/index.html#appendix1
NDSF SM2000 survey planning doc, *http://www.whoi.edu/page.do?pid=11303*
IVS3D Fledermaus Pro, *http://www.ivs3d.com*
Matlab, *http://www.mathworks.com*
Submeter bathymetric mapping of volcanic and hydrothermal features on the East Pacific Rise crest at 9 degrees 50 ' N, Ferrini, V. L.; Fornari, D. J.; Shank, T. M.; Kinsey, J. C.; Tivey, M. A.; Soule, S. A.; Carbotte, S. M.; Whitcomb, L. L.; Yoerger, D.; Howland, J. , Geochemistry Geophysics Geosystems, Jan 19, Volume 8, p.-, (2007), Doi 10.1029/2006gc001333

Contact the NDSF data manager, NDSFDataMgr@whoi.edu
Example scripts for MB-system, Sonardyne USBL.
DSL renavigation software
Imagenex processing software and cookbook

Pre-dive/pre-survey Setup

To be performed by science observer. ssumes use of Seabat 7125 system.

Prior to the start of the survey, confirm function and settings of the Reson 7kCenter control program.

1. Confirm that real-time sound velocity measurements are being delivered to Reson 7KCenter. Do this under the *Oceans* tab, *Sound Velocity* slider by moving the slider off its value and observing that after a few moments it changes to a new value. If delivery has failed, use the chart in section 7.3.3.3 of the Seabat 7125 Operator's Manual (page 70) for recommended values.

2. Confirm operating set up.
Auto pilot mode is recommended because it increases the likelihood of a successful collection of survey data; one reason is that it reduces demand on the

slow network connection between in-sphere client computer and the frame-mounted primary control computer. There is an increased chance of losing client display and control of the sonar system when exercising manual mode.

Auto pilot takes most configuration responsibility, and choice, out of a user's hands. Should the user prefer to operate the system manually, the following are recommended settings for a survey performed at 60 meters altitude.

☐Survey design from science has been transferred to Expedition Leader and Pilot. Using remote laptop VNC or Remote Access:

Pre-Launch section, to be completed by Alvin personnel.

☐Turn on Reson iCPU and login.
username reson
password reppe

☐Tardis is running, time is synced to the Alvin NTP server.
check in Control Panel/Administrative Tools/Event Viewer for recent synchros

☐Destination folder for raw data files created. System has >= 5GB free space.
D:\<cruise_name>\<loweringID>

☐Haxxio UDP-Serial Port Redirector is running.

☐ Press start on the 7K Control Center, bring up the GUI
default xml setup file is 400kHz, equidistant

☐Check the BITE status, make sure all lights are green.
Errors may appear if Jason is still on deck.

☐ PDS2000 I/O module is running *a tab is 7K Control Center*

☐External timer/trigger module setup invoked, if applicable.
Requires prior configuration of DVL for external triggering mode. The timer board is set by a Docklight script under ET or pilot control.

7K Control Center Settings

gates tab

☐ No gates *adaptive gates should be considered- potentially valuable, but a somewhat unknown quantity.*

ocean tab

☐ absorption 60

☐ spreading 27 *adjust to reduce noise.*

☐ sound speed
In ocean tab, move sound velocity value slider off position, confirm it moves to register newly ingested data.

main tab

 range 150 *profile at wedge bottom*

 max rate 5.0

 gain 20 *adjust for strong clean profile*

 pulse length 60us

 transmit power 220 *in water only, or briefly on dec*

trigger tab
Depends on which DVL sensor is being used.

☐ input disabled, *if the 1200 kHz DVL*

☐ input active, *if the 600 kHz DVL*
main: max rate apparently must be set before triggering is enabled

data recording tab

☐ recording 7000 7004 7006 (7007)
7007 *collects data for backscatter. Record unless science requests otherwise. However, as of this writing, MB-system does not recognize record 7007 for its backscatter processing.*
IMPORTANT: *depending on version of 7K Cntrol Center, upon start of recording a dialog may ask if record type* 7018 *should be recorded. NO! (answer "continue without"). Recording 7018 will slow down the system enough to crash.*

☐ Outfile path set to *D:\<cruiseid>\<divenum>*