Processing Lidar Data for Charting Applications – Understanding the Trade-Offs and Challenges

A variety of acoustic and optical technologies are able to be used to survey shallow water areas. Due to the basic physical principals of their design and platform on which they are deployed each type of technology has inherent, relative, advantages and disadvantages in terms of accuracy, efficiency, safety, speed, resolution and discrimination. Determining what type of survey tool is best suited to execute any given survey requirement is a very important exercise. One of the important fundamental considerations in planning, executing and reporting hydrographic surveys is the requirement to detect small objects on the seabed.

Evaluation of the object detection capability of different systems has been an ongoing activity within the industry for many years. In a contemporary context, manufacturers and users of different acoustic technologies have spent considerable effort establishing the relative capabilities of most commercially available systems. In the general hydrographic community significantly less understanding exists of the capabilities of airborne LIDAR systems in this area. This paucity of information is due to a variety of reasons however the relative dearth of manufacturers and operators probably is the most significant issue. The intent of this paper is to describe several of the issues that impact the object detection capability of airborne LIDAR bathymetry systems, illustrate these issues via a case study and then describe important areas of development.

Discussion of Object Detection by LIDAR Bathymetry

Airborne LIDAR bathymetry systems were developed as fast, shallow water, depth sounding systems ideally suited to shallow and dangerous areas with clear water. The requirement for detecting small objects on the seabed, manifest in practical terms as the System Detection Capability described in table 1 of the IHO Standards for Hydrographic Surveys, 4th Edition, Special Publication no. 44 IHO as a 2m cube, is a relatively new requirement. Although not designed specifically to meet the object detection criteria, when operated in the appropriate configuration and suitable conditions LIDAR bathymetry systems are able to meet the IHO requirement, detecting a 2m cube with a confidence of 95%. This has been proved through actual tests conducted by manufacturers, operators and third party organisations. In the case of the Laser Airborne Depth Sounder (LADS) technology 2m cubes located in depths of 10m, 15m and 20m have been used as the basis of proving the capability using empirical analysis.

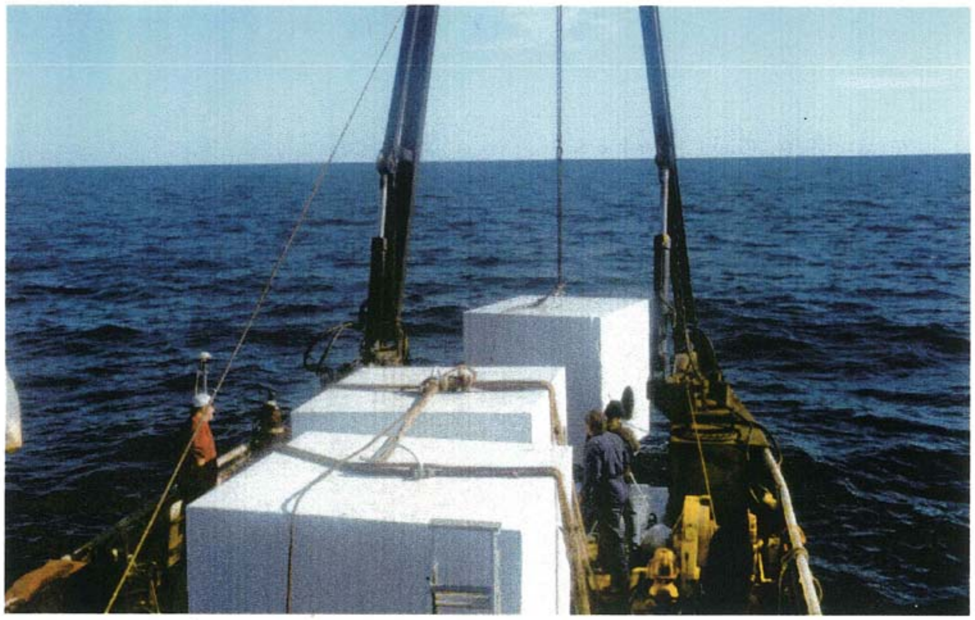
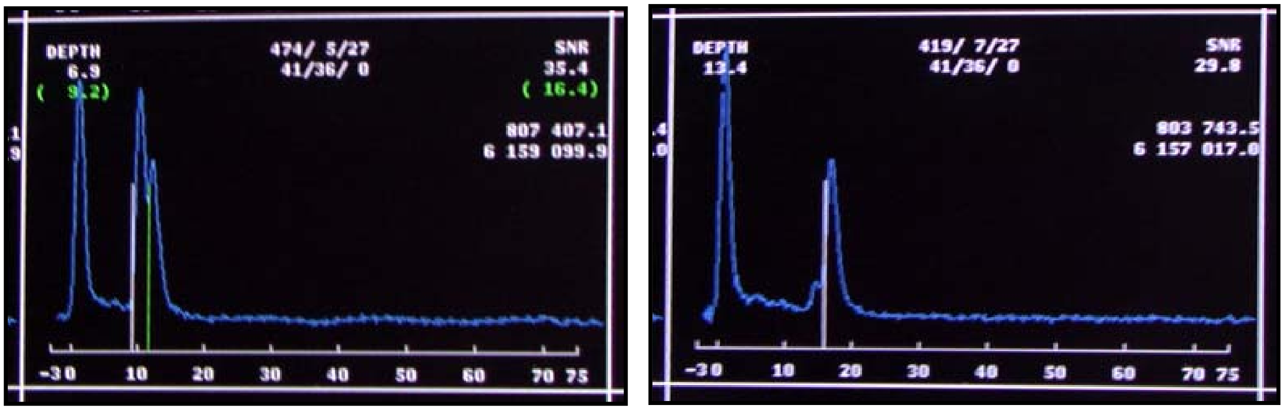


Figure 1 – Deploying the First Target[1]



High Amplitude ("Direct Hit") Low Amplitude ("Glancing Blow")

Figure 2 – Example Target Strike Waveforms – High and Low Amplitude

In order to explain in detail the caveats of *appropriate configuration* and *suitable conditions* it is necessary to describe several characteristics of LIDAR bathymetry systems. But basically at the highest level the issues are those of any remote sensing system, the sampling resolution and the quality, or signal to noise ratio, of the data being collected. At this level LIDAR and acoustic systems are the same. More specific details regarding LIDAR characteristics follow.

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[1] Since deployment these highly reflective targets have been covered by non-reflective biological (weed) growth.

Beam Size and Energy Density

The LIDAR beam size is relatively large in order to meet laser eye safety requirements. Generally the LIDAR sounding area on the seabed is larger than the IHO object area. Hence the signal return from the object is lower than that from normal seabed soundings and therefore the thresholds used to detect objects need to be lower than those used to detect the seabed. In some cases with a direct strike on a target in very shallow water the majority of the return energy may come from the object but this is less common than a partial illumination, examples of both are shown in figure 2. This issue is one of sounding energy density, acoustic systems have similar issues however in general the footprint is smaller than that of LIDAR (excluding SBES). As the sounding energy density within a pulse reduces, the return energy, or signal, from the IHO Order-1 size object decreases making it harder to detect.

Turbidity, Sea State and Scattering

The issue of sounding energy density is, critically, a function of environmental parameters. For LIDAR, turbidity and sea state both impact the sounding energy density on the seabed. As the LIDAR beam propagates through air to water interface it is refracted, in conditions with significant sea states the sea surface facets (waves) cause an effective broadening of the laser beam, this in return reduces the sounding energy density and results in a lower return signal strength from the object. Similarly turbidity results in scattering of the laser beam and a subsequent reduction in the sounding energy density, again resulting in a lower return signal from the object. The empirical testing conducted with the LADS technology has been conducted to a maximum depth of 20m, beyond this depth the impact of turbidity and sea state would mean object detection could only be considered achievable in ideal conditions.

Turbidity and Beam Attenuation

In addition to the scattering effect described above turbidity significantly increases the attenuation of the optical signal, decreasing the amplitude of both a normal seabed return and returns from objects. As returns from objects are smaller than those from a flat seabed area the impact of signal attenuation has a greater effect on object returns than returns from the seabed. The implication of this is that not only does turbidity impact the maximum depth range of LIDAR systems and the ability of systems to detect objects, but it effects the object detection capability more markedly. In an absolute sense the impact of turbidity is defined by the level of background noise; in effect the noise floor is set, mainly by solar radiation, and once the turbidity attenuates the optical signal such that it is less than the noise floor no detection is possible.

Turbidity and False Detects

The third impact of turbidity in the context of object detection is that as it may not be uniform through the water column it is possible that varying levels of backscatter may produce a waveform that “appears” to be a return from an object. Figure 3 includes an example of a return waveform that shows this structural backscatter that could be interpreted as an object.

Figure 3 – Turbid Water, High Noise Floor, Structural Backscatter

Object Reflectivity

The nature of the object also impacts the ability of LIDAR bathymetry systems to detect them. In an analogous situation to the dependence of acoustic systems on acoustic signature of an object, the ability of LIDAR systems to detect objects is dependant on the reflectivity of an object. Objects that are less reflective than the surrounding seabed will return a relatively lower optical signal for a given surface area and therefore have a lower chance of detection. Conversely objects with a higher reflectivity than the surrounding seabed will have a higher probability of detection. For example this issue is important for areas where kelp (low reflectivity) may be prevalent on rocky outcrops in otherwise sandy (high reflectivity) areas.

Object Dimensions

An earlier paragraph discussed the sounding energy density and the impact it had on the ability to detect objects on the seabed. The lower the amount of energy returning from the object the lower the likelihood of detection. The corollary of this is that as objects become smaller they are more difficult to detect. The size of the optical signal returned decreases directly with the effective surface area of the object illuminated by the sounding. The height dimension of the object has a different but significant impact. The processing of LIDAR returns is based on time domain reflectometry, the ability of LIDAR systems to detect what are effectively step changes between the depths of small objects and the depths of the surrounding seabed is dependant on the time domain response of the returned LIDAR pulse. The impulse response of acoustic signals in the underwater environment has a higher bandwidth, therefore faster time domain response, than that of optical signals. This relatively slow time domain response means that as the step change in height between the object and seafloor (object height) reduces the returned optic signal tends to merge into a single pulse that is difficult to robustly process for the detection of small objects. For the LADS system tests on varying sized objects has resulted in objects less than a height of 1m being detected, however objects this size are not detected with the same statistical confidence as the 2m cube. All empirical analysis conducted to establish the capability of the LADS system to detect small objects to a 95% confidence has been based on a 2m cube.

Thresholds for Noise Rejection and False Detects

The discussion so far has centred on issues that impact the strength of the returned optical signal from the object, either absolutely, or relative to the returns from the surrounding seabed and base noise level. The processing of the returned waveforms also impacts the probability of detecting small objects. In the LADS system detecting small objects involves processing the returned waveform in two phases, firstly to detect what is the surrounding seabed depth and then concentrating on the leading edge of the returned pulse, and immediately prior to it, apply lowered amplitude thresholds to detect smaller returned signals that are attributable to small objects. The setting of this threshold effectively determines two things, the chance of detecting objects of a specific size but also the chance of allowing noise pulses to be "detected" falsely as objects. Therefore the appropriate setting of thresholds to improve the percentage chances of object detections but also to discriminate against noise is an important consideration.

Sounding Resolution

All of the discussion above describes the ability of a LIDAR system to detect a small object if the LIDAR sounding is incident on it. One significant difference between LIDAR and acoustic swath systems is that LIDAR has a materially lower resolution. Soundings separation, or the distance between neighbouring soundings, is typically in the order of whole meters. This resolution is, in part, defined by laser eye safety issues but it is also a function of the speed of the airborne platform and the repetition rate of the laser transmitters. It is intuitive that if a system is going to survey an area materially faster than any other system it's resolution will be less. Therefore because the spatial density of LIDAR sounding is comparable with the size of objects to be detected a low number of LIDAR soundings may be incident on the object. This makes statistical processing or cleansing techniques, which are powerfully employed with swath acoustic systems, inappropriate for LIDAR due to paucity of data points. Furthermore the issue of resolution determines that the statistical probability of detecting an object becomes a function of sounding pattern resolution. It is generally accepted that 3 x 3 sounding pattern with 200% (ie: sounded twice) coverage is required to meet the 95% probability criteria of the IHO specification for the detection of the 2m cube. This is supported in the case of the LADS technology by empirical analysis of 2m cubes at depths of 10m, 15m and 20m.

Case Study – Long Island Sound

The intent of this case study is to further clarify the issues that effect object detection by LIDAR bathymetry based on an actual survey. Areas of seabed in Long Island Sound were surveyed by the LADS Mk II LIDAR system and were subsequently surveyed by NOAA Ship Thomas Jefferson using acoustic systems. Large parts of these surveys contain areas of seabed where numerous features exist. This provides an extremely valuable data set for the analysis of object detection by the LADS Mk II LIDAR system.

The water clarity in Eastern Long Island Sound was closely monitored from April 2003 throughout the year as conditions became marginal in early summer. The survey was deferred and finally commenced in early 2004 when water conditions improved. However some parts of the survey area remained turbid, and in others, significant changes in turbidity occurred. These difficult conditions complicated data collection and processing, and some areas were resurveyed a number of times, in an attempt to overcome gaps due to turbidity. Data collection was completed in early March 2004.

NOAA ship, Thomas Jefferson, was subsequently tasked to junction with the LIDAR survey in Spring 2005, and to evaluate the object detection performance of the LIDAR survey.

Twelve common areas of different depths have been identified which contain numerous objects of different size. From the initial investigation, only 28 of a total 93 objects were identified by LIDAR. The results were published in "Empirical object detection performance of lidar and multibeam sonar systems in Long Island Sound" [IHR 7, 2, (August 2006), 19-27] by LCDR(NOAA) Shepard M. Smith. The publication by its own admission was essentially a report of empirical results with limited analysis; the data was subsequently passed to Tenix LADS for analysis. The intent of this case study is to further consider the results in the context of the issues that effect object detection using LIDAR bathymetry. Specifically the survey was conducted in varying environmental conditions, particularly turbidity, with a combination of 3 x 3 meter and 4 x 4 meter sounding resolutions and coverage achieved in most areas of 200% but in some areas only 100% coverage. With this range of survey parameters the issue of where small objects may have been reasonably expected to be detected becomes complex, the best areas would be where data not effected by turbidity was collected with 200% coverage and a 3 x 3 sounding pattern. Then to further complicate the analysis the object sizes and dimensions, as determined from the MBES data, vary significantly. To demonstrate the complexity of the issue and to provide further analysis of the empirical results consider the following:

- 31, or exactly one third, of the 93 objects have a height 1 meter or less. This is half of the IHO requirement, although it is the height that NOAA has defined as significant for object detection. As described previously the height of objects impacts the ability of LIDAR systems to detect objects because of the impulse response of the optical return. Although heights less than 1 meter are able to be detected using LIDAR, and in fact in this survey several were detected to a minimum detected height of 50cm, it should not be considered that to a 95% confidence level that they will be detected.
- Of the 62 objects with a height greater than 1 meter 26 were in areas surveyed with a 4 x 4 meter sounding pattern. Several of these objects were probably larger than the 2m cube however only object length was provided so it is difficult to further categorise on this aspect. Objects will be detected with a 4 x 4 sounding pattern however it should not be considered that objects the size of the IHO cube will be detected with 95% confidence.
- Of the 36 objects greater than 1 meter high and surveyed in areas with a 3 x 3 sounding pattern 4 were in areas that was sounded with only 100% coverage. During data collection all of the areas were flown with at least 200% coverage, some as much as 600%, but in the final assessment of data only 100% coverage was deemed suitable for delivery in some areas. Again, objects will be detected with 3 x 3 100% coverage but not with 95% confidence.

Based on the basic categorisation above 32 objects should be considered in an assessment of the object detection capability of LIDAR bathymetry. The following analysis is by necessity a simplification because not all of the information for a definitive investigation is available, for example, no useful information is known as to the reflectivity of the objects or the surrounding seabed and the dimensions of the objects is not known. In all likelihood several are larger than the 2m cube but equally some may be smaller. Also critically no specific information is available with respect to the levels of turbidity or sea state that were evident at the time of data collection, although in the case of turbidity the general consensus is that the water clarity was marginal for LIDAR bathymetry. However in order to facilitate the case study and provide a platform for some meaningful analysis it is assumed the 32 objects should be detected with 95% confidence in accordance with the IHO requirement.

Of the 32 objects included in this subset 11 were identified in the final approved dataset provided by Tenix LADS to NOAA[2]. This is significantly less than the IHO 95% requirement. Each of the contacts identified in LCDR Smith's paper was investigated in the collected LIDAR dataset with the original waveforms from the each location being re-examined. Analysis of the LIDAR waveforms from the locations identified by LCDR Smith and the workflow that was undertaken in the original processing of the data is considered in the following discussion.

This analysis provided a mechanism for classifying the 21 objects not included in the final LIDAR data. The following results were obtained:

- In 9 cases the automatic processing algorithms had actually successfully detected the object. However during manual processing[3] the objects had been removed from the dataset. The manual process in effect had over cleaned the data. The cause of this over cleaning is considered to be the generally high level of noise in the data as a result of turbidity. A lot of manual editing had occurred and in these 9 cases the return signal from the object had been interpreted as noise on the waveform and removed. As described previously one issue of turbidity is that it does produce artefacts on the waveforms that can be interpreted as objects.

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[2] Interestingly this again emphasises that LIDAR will detect objects that are less in height than 1 meter, with a 4 x 4 meter sounding pattern and with 100% coverage because 15 of the total 28 objects identified by LIDAR occurred with these parameters.

[3] A hierarchical level of manual processing was conducted for this survey in accordance with standard, accredited, operating procedures. Data was processed, validated and checked by surveyors prior to area based QC and finally approval from a Cat A qualified surveyor.

```
135.1.1
82/3/1
41/42/0                  DEPTH SNR
                    SH: -0.5 23.5
                    B1:  6.0  3.7
                    S1:  7.3 26.7
```

```
136.1.1
95/12/28
35/46/0                  DEPTH SNR
                    SH: -0.6 27.7
                    S1:  6.0 19.2
                    S2:  7.9 13.8
```

```
K  -  135.1.1    SV  19  VALIDATED  L
+  -  64.0.1     SV  14  VALIDATED  .
Y  -  65.0.1     SV  14  VALIDATED  .
>  -  133.0.1    SV   9  VALIDATED  .
A  -  134.2.1    SV  20  VALIDATED  .
<  -  136.1.1    SV  19  VALIDATED  .
0  -  137.1.1    SV  19  VALIDATED  .
0  -  603.0.1    SV  15  VALIDATED  .
```

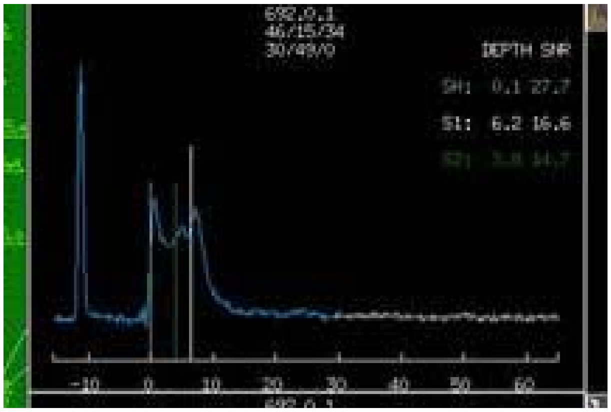
```
MAIN REGION: FIXED                         (6.7,8.3)
NAVIGATION REGION: FIXED                   (-16.5,10.2)
COLOUR SOUNDINGS BY:  DEPTH  RUN
```

```
29 SEP 2005 14:25:50
SORTIE: 19    RUN: 135.1.1          DATE: 25 FEB 2004
  F/R/C      : 82/3/1                 DISPLAY: NBA      -ALL_CHILDREN
  TMC        : 734 422,4 574 803      TIME    : 18:43:29 25/02/04
  RUN ID     : 135.1.1                ATTRIB : ___w______d____
  VAL STATUS: ACCEPTED                DEPTH   : 7.30

14:21:37 RUN 130.1.1 HAS BEEN DESELECTED
14:21:41 LOADING RUN 135.1.1 ...
14:21:55 YOU MAY NOW CONTINUE
ENTER SELECTION (1..16):(1)
T,PGUP:MOVE AREA FW E,PGDN:MOVE AREA BW D,LEFT:SCROLL LEFT  G,RGHT:SCROLL RIGHT
  R,UP:SCROLL UP    F,DOWN:SCROLL DOWN    Z,MC:ZOOM IN         X,MR:ZOOM OUT
```

Figure 4 – Automatic algorithms successfully detecting object subsequently removed in manual cleaning. Local Area Display showing selected waveforms (with manual edits) and all surrounding depths.

- In 7 cases the automatic processing algorithms had not detected the object however on visual inspection of the waveform it is evident some return signal from an object is apparent.

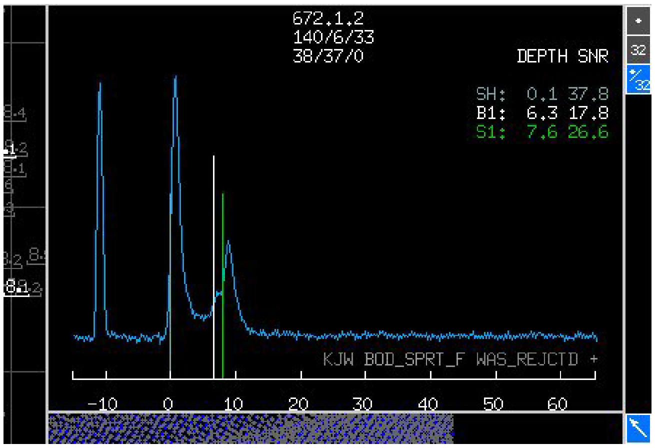


```
692.0.1
46/15/34
30/49/0                  DEPTH SNR
                    SH:  0.1 27.7
                    S1:  6.2 16.6
                    S2:  3.8 14.7
```

Figure 5 – No automatic detection, but visual inspection indicates some energy from a small object. Single waveform shown.

- In the final 5 cases the levels of turbidity were such that no return signal from a small object was evident. In these cases the SNR for the seabed return itself was marginal.

The next step in the case study was to implement a more rules based processing methodology, re-process the data and assess if this produced an improvement in object detection. That is, establishing purely quantitative measures for determining whether the automatic waveform processing for small objects had produced valid contacts. In the LADS system the specialised algorithms to detect small objects on the seabed are referred to as BOD (Bottom Object Detection) algorithms. To assist the operator interpret waveforms during manual editing the processing software produces measures of the relative signal strength of the return signal from the seabed and then also, independently, the relative signal strength of the BOD signal. These parameters are referred to as SNR and BOD SNR. The example waveform below in figure 6 shows these indicated to the operator (top right corner of the figure).



```
672.1.2
140/6/33
38/37/0
                DEPTH SNR
          SH:   0.1 37.8
          B1:   6.3 17.8
          S1:   7.6 26.6
KJW BOD_SPRT_F WAS_REJCTD +
```

Figure 6 – Waveform showing seabed depth of 7.6m with SNR of 26.6 and BOD depth of 6.3m with SNR of 17.8.

For the rules based processing approach the BOD SNR was used to filter all waveforms at a set threshold, in this case 13 dB. 13 dB was selected because it was calculated to represent 4.5 times the amplitude of the noise floor (random noise including electric signal and solar radiation) which was considered adequate for robust noise rejection. Following the automatic filtering no further manual editing was performed. The results of this rules based re processing on the 32 objects were as follows:

- 26 of the 32 objects were detected by the automatic BOD processing algorithms with signal strength above the threshold, including all 11 of the objects included in the original manually processed dataset,
- 4 of 32 objects were detected by the automatic BOD processing algorithms but the signal strength was below the threshold,
- 2 of 32 objects were not detected by the BOD algorithm

The clear outcome is that using a rules based processing approach materially improved the object detection outcome achieved, in fact a 135% improvement. However even with this improvement the outcome is less than the 95% confidence specified in the IHO requirement. The logical extension of this is that the environmental conditions, particularly turbidity, were such that only 81% of objects were detected not the required 95%. Anecdotally this proposition is supported because the survey was conducted in generally turbid conditions. The issue becomes communicating to the charting authority, in this case NOAA, what areas of the survey were impacted by turbidity to the extent that IHO Order 1 object detection was not achievable. In the case study for example if the objects not detected in the data could have been isolated as discrete geographic area(s) which had particularly bad turbidity then these area should have been identified as not meeting the IHO Order 1 requirement for object detection.

The outcomes of this case study are that I) LIDAR did detect a number of objects but the manual editing of the Long Island Sound data led to an over cleaned dataset that omitted small objects and II) the circumstances under which object detection by LIDAR should be reasonably expected were not clearly enunciated in the Report of Survey. These issues are vital in establishing an understanding within the user community as to what are sensible expectations of LIDAR bathymetry with respect to object detection.

Recommendations and Areas for Development

Two clear areas for development are apparent from the discussion and case study in this paper. Firstly there are specific recommendations that can be made to the data collection phase of LIDAR surveys to maximise the ability of systems to detect small objects on the seabed. These recommendations come from an understanding of what effects the ability of LIDAR bathymetry systems to detect objects as discussed in the first section of the paper (Discussion of object detection by LIDAR bathymetry). Secondly the case study indicates that the implementation of rules based approach to processing, thereby reducing the level of subjective decision making, can improve the object detection capability of the systems[4]. Certainly a more robust rules based approach will make results more repeatable which then provides the ability to develop a method of objectively reporting the outcome of a survey in terms of object detection expectations. This is an important development for ensuring the user community is able to quantify the utility of the data provided.

Data Collection Recommendations

In making recommendations with regard to the execution of LIDAR bathymetry surveys and maximising them for object detection it needs to be understood these are guidelines that may restrict, significantly, the operating efficiency of airborne LIDAR systems. A conservative approach that effectively mandates that all areas flown by LIDAR need to be maximised for object detection will negate the efficiency advantages gained from employing these systems. Notwithstanding this the following recommendations can be made to the data collection phase of surveys to maximise the ability of LIDAR bathymetry systems to detect small objects on the seabed.

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[4] It is also to important to note that a strictly rules based approach may increase the level of noise present in data from the seabed if processing thresholds are not optimised appropriately

The sounding energy density should be maximised whilst maintaining laser safe operations including suitable safety margins for an observer at the sea surface. Recall that in an absolute sense at the sea surface the sounding energy density is constrained by issues of laser eye safety. However it is important the sounding energy density is as high as possible to maximise the ability of the LIDAR system to detect objects, in this regard monitoring laser transmit power is important. From the sea surface to the seabed the sounding energy density is reduced by higher sea states and higher turbidity therefore operating in calm conditions with periods of low turbidity is recommended. All systems have different receiver characteristics and sensitivities however in each case the amount of energy returned from a small object to the receiver will be a function of sounding energy density, the higher returned energy the greater the chance of detection.

Of course the absolute seabed detection by LIDAR bathymetry systems is also negatively impacted by sea state and turbidity, but object detection is a more difficult requirement. Based on the experience of Tenix LADS and as guide if a system can operate to detect the seabed accurately in a sea state of 3 to a maximum depth of 2.5 times the secchi disk depth then to achieve object detection to meet the IHO Order 1 requirement the maximum sea state may be 2 to a maximum depth of say 1.5 times the secchi disk depth. It is expected these general relationships could be used as a guide to depths of 20m (as supported by empirical testing), however in depths greater than this it is considered unlikely the IHO Order 1 requirement would be met in anything but ideal conditions.

Another technique to improve the relative signal strength of the seabed and object returns is to reduce noise from solar radiation. This is achieved by flying at night. The signal strength would also be improved by flying at a low height, signal strength at an aircraft height of 1200 feet will be stronger than that with an aircraft flying at 2200 feet.

The previous recommendations have concentrated on improving the signal strength of the return from an object. The other important aspect is to ensure the spatial density of soundings is sufficient. Areas should be sounded either at 3 x 3 with 200% coverage or with a 2 x 2 pattern. Again it should be noted that the selection of sounding pattern has a significant impact on the efficiency of LIDAR bathymetry systems. Spatial densities less than 3 x 3 are not suitable for detecting IHO sized objects with a 95% confidence level.

The following guidelines could be considered therefore to maximise object detection and meet the 95% confidence requirement of the IHO specification:

- spatial resolution of either 2 x 2 or 3 x 3 with 200% coverage
- maximise relative strength of signal return via
  - flying at night
  - flying in only sea state 2 or less
  - flying when water is clarity is such that depth achieved will be 1.5 times secchi depth
  - flying at lowest possible altitude
  - flying with maximum sounding energy density

As mentioned previously it should be noted that imposing these guidelines may significantly impact the efficiency of a LIDAR bathymetry survey, which is one of the key drivers for using the technology.

Areas for Development

The case study indicated the potential for improvement in object detection by LIDAR through the implementation of a clear rules based processing mechanism that maximises the ability of systems to detect small objects. It should be noted such a mechanism must also provide sufficient noise rejection to prevent “false detections” of noise pulses. Developing such rules based processing mechanism of course directly leads to the ability to provide a quantitative assessment of what level of object detection has been achieved at the completion of a survey. This is an important area for development of LIDAR bathymetry systems in terms of allowing the outcomes of surveys to be assessed.

In the same manner that environmental conditions make the maximum depth of a LIDAR bathymetry survey difficult to predict prior to data collection the object detection outcome is also hard to predict. However for the maximum depth the outcome is easy to assess once the survey has been complete; depth bathymetry data exists or it doesn’t. However in the case of object detection the situation is not this clear cut. If depth data exists there is no qualification on its ability to detect small objects, clearly there should be.

The methodology being pursued for the LADS technology is one of defining outcomes spatially. That is for a given survey area the total area(s) within which object detection is assessed as being suitable to meet the requirements of the IHO95% confidence requirement for the 2m cube would be defined. The algorithms used to assess whether the data is suitable for object detection need to incorporate the issues discussed previously in this paper; spatial resolution of soundings, sounding energy density and signal strength of return energy. Generally the methodology being considered is:

- Spatial resolution needs to be 2 x 2 or 3 x 3 with 200% coverage
- Sounding energy density needs to be sufficient such that objects the size of a 2m cube are able to be detected in appropriate conditions
- BOD algorithms need to be activated and run on the data (this is a user selectable setting in the LADS system)
- The relative signal strength of the laser returns needs to be sufficiently high for the BOD algorithms to reliably detect a small object. This criteria effectively considers issues of turbidity, sea state and water depth.

The first three criteria can be determined easily however the quantitative assessment of the signal strength is an area of development. It needs to consider the seabed return and whether it has sufficient signal strength such that if a small object was present it would return sufficient energy for the BOD algorithms to detect it. The methodology being pursued for the LADS technology is to assess the signal strength of the seabed return and from this make a determination of whether an object would be detected if it was present on the seabed. To use this approach assumptions need to be made regarding the effective spreading of each LIDAR pulse through the water column and the surface area of the object to be detected. The concept is most clearly described using a simple example.

Consider a 2m cube in 10 to 15 meters of water depth that has 75% of its surface area illuminated (a partial illumination). Using an estimate that the pulse on the seabed from which seabed energy is returned would be 4m in diameter at that water depth the surface area of the return from the object is 25% of the total returned energy (4m diameter spot equating to approximately 12 sq m). Using 20 log calculations for SNR this means the BOD signal will be 12 dB lower than the signal from the seabed. Combining the 12dB figure with the criteria from the case study that the BOD SNR should be 13 dB above the noise floor a simple sum results in a required signal SNR of 25 dB being required to successfully extract small objects from the signal. In this simple case all waveforms with an SNR greater than 25 dB would be flagged as suitable for meeting the object detection criteria of IHO order 1 and those less than 25 dB would be flagged as not suitable[5].

The issue for object detection by LIDAR bathymetry is one, in the first instance, of eduction. The community needs to understand the issues involved and limitations of object detection by LIDAR bathymetry but equally the responsibility is with the providers of services to clearly and unambiguously report what has been achieved in the context of object detection for each survey. Put simply at completion of a survey what has been achieved should be clearly reported.

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[5] It should be noted that the quoting of these dB figures is specific to the LADS technology given assumptions in how they are calculated. The figures should be regarded as bespoke, relative measures rather than absolute figures that could be applied to other systems. Having said that the concept could still apply.