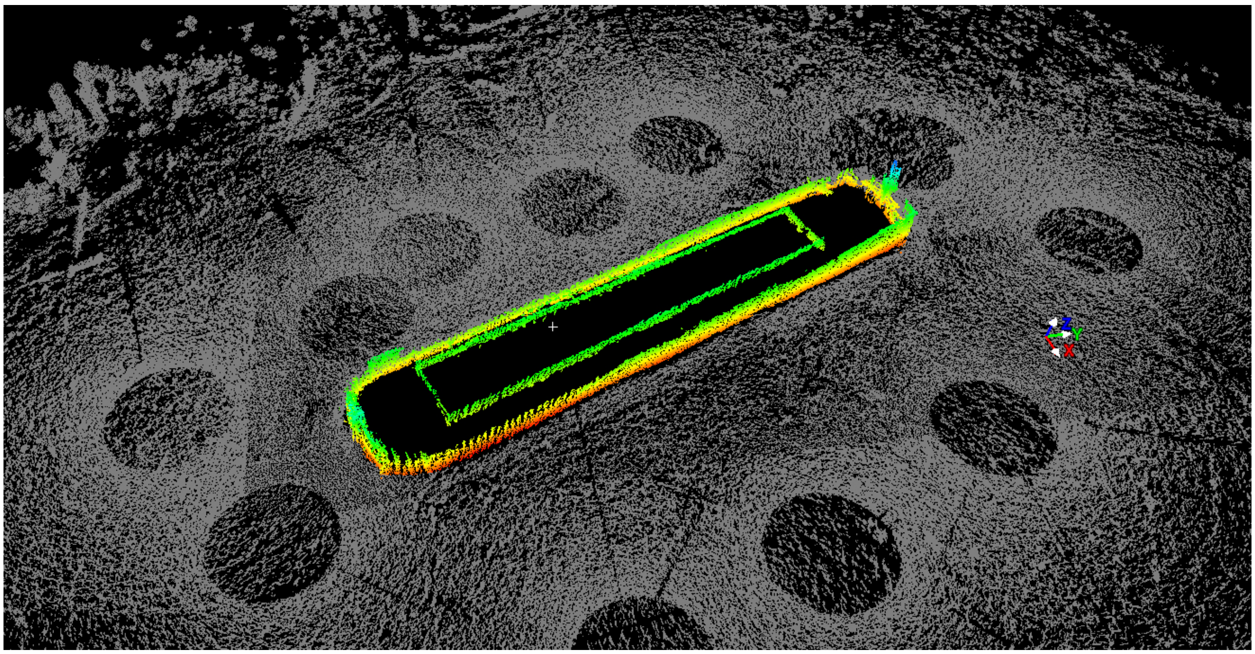
Manual of Best Practices for the Employment of Mechanical Scanning Sonar in the Documentation of Submerged Cultural Resources



Prepared For:

National Center for Preservation Technology and Training

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Manual of Best Practices for the Employment of Mechanical Scanning Sonar in the Documentation of Submerged Cultural Resources

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ABSTRACT

This *Best Practices Manual* is a document designed to instruct the public and cultural resource managers in the most effective use of the emerging technology of mechanical scanning sonar in the study, management and preservation of submerged archaeological remains. The document is presented in an easily understandable format with the goal of not being encyclopedic in content, but providing readers a summary of the topic and references for more in-depth study.

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INTRODUCTION

Mechanical scanning sonar is an emerging technology that has many useful applications in the understanding and documentation of submerged cultural resources. This technology employs a sonar unit in much the same fashion that laser scanners have been used to document structures above water, except it uses sound instead of light to capture measurements. A mechanical scanning sonar system consists of a sonar head mounted on a pan and tilt unit atop a tripod. When activated this unit emits, and receives, a vertical "fan" of sonar signals (Figure 1). As this fan is panned across an object detailed sonar data is collected. When the scan is complete the system software is able to combine the many thousands of individual sonar measurements into a detailed point cloud depicting the structure it is scanning in three dimensions (Figure 2). If the same structure is scanned from a number of different locations and angles the individual point clouds generated from each scan can be stitched together to form a composite point cloud of the entire structure (Figure 3).

Figure 1: Mechanical Scanning Sonar (Teledyne-BlueView)

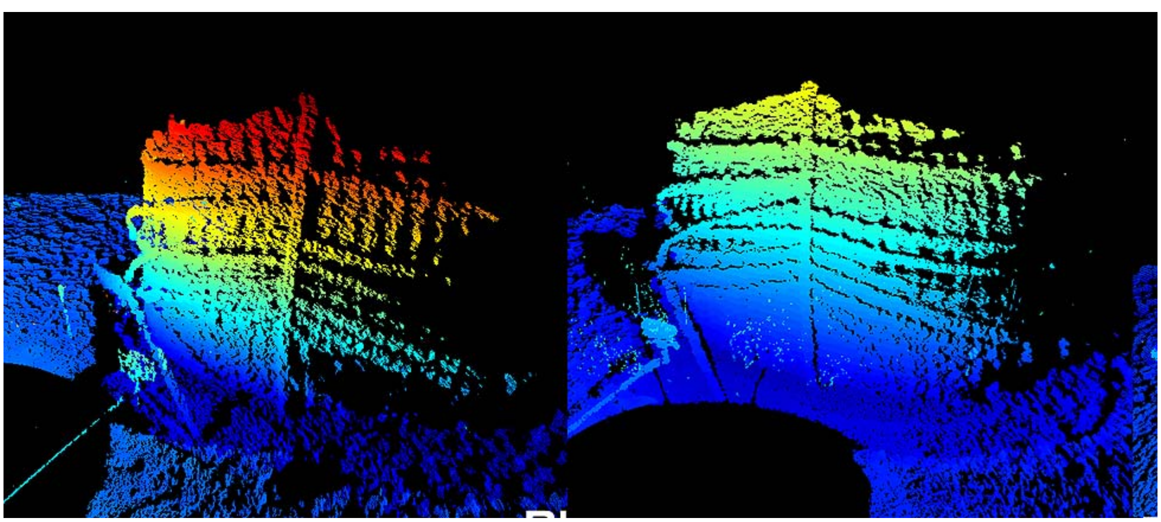

Figure 2: Two scans of the bow of the Sloop Island Canal Boat (LCMM Collection)

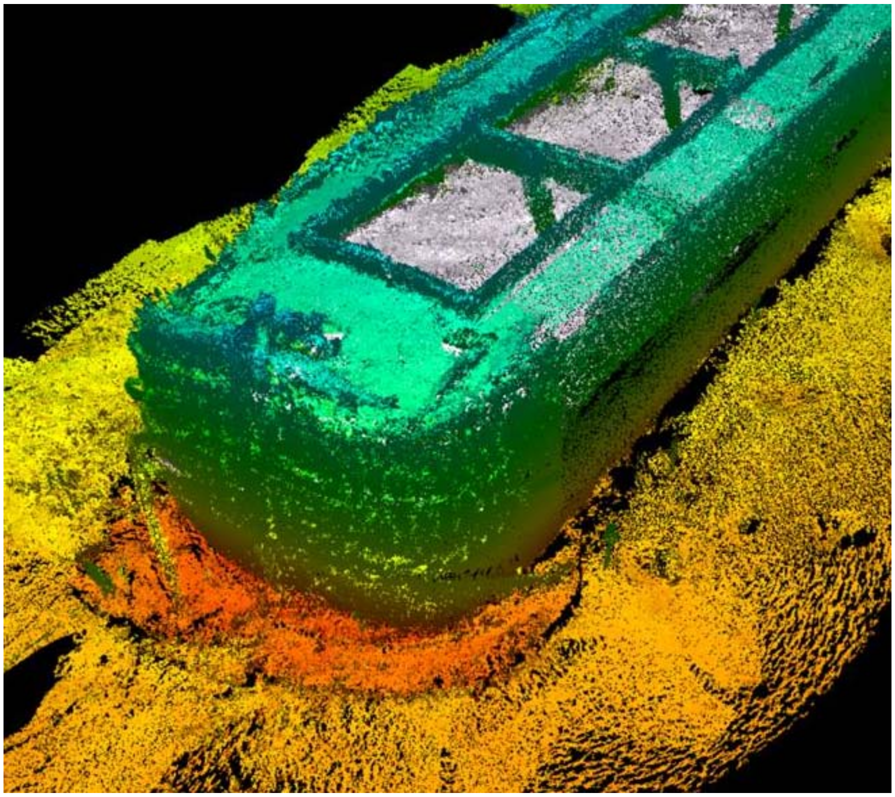

Figure 3: Composite point cloud of the bow of the Sloop Island Canal Boat (LCMM Collection)

The abilities of this unit make it a powerful tool in the tool box for the nautical archaeologist. It rapidly captures an incredible amount of information with sufficient detail to meet many of the requirements of a cultural resource manager. While this technology cannot currently replace the need for in-water documentation of fine details from an underwater feature, proper employment can greatly aid with the planning, organization, and overall understanding of a site in a fraction of the time required to document a comparable level of detail using traditional underwater archaeology methods.

The purpose of this manual is to instruct cultural resource managers who may not be familiar with technology about its abilities and the Best Practices that should be employed to achieve the most accurate and efficient data recovery efforts. The document is presented in an easily understandable format with the goal of not being encyclopedic in content, but providing readers a summary of the topic and references for more in-depth study.

RESEARCH POTENTIAL

The application of this technology to the management of submerged cultural resources offers enormous potential. The relative speed with which detailed three dimensional information about a submerged structure can be captured makes this technology a powerful and attractive tool. Additionally, the fact that this technology preforms as well in low visibility environments as it does in clear water makes it a logical choice for situations where other, visibility dependent, techniques are not practical.

In additional to mechanical scanning sonar other new technologies for rapid collection of three dimensional point cloud information from submerged cultural resources are also under development and study. These other technologies include the use of underwater laser scanners and the photogrammetry technique, which employs pixel data from over lapping digital images to create three dimensional models. Each of these technologies has advantages and limitations. This document will make the reader aware of the advantages and limitations of mechanical scanning sonar so that they can make an informed decision about the proper documentation technique to achieve their research goals.

METHODOLOGY

RESEARCH DESIGN CREATION

All archaeological investigations begin with the creation of a Research Design document. Creating a Research Design involves outlining the goals of the overall project, with regards to planning, implementation, methodology and result reporting. The research design will guide the project from start to finish, be presented to state and federal officials that issue the permit for the project, and enable the many stages and components of the project to be detailed and presented to the community, potential partners and funding entities. It should complement the local and federal archaeological standards and guidelines for the carrying out an archaeological and/or historical investigation.

The development of a realistic research design that includes the use of mechanical scanning sonar requires a thorough understanding of this technologies abilities and limitations. Therefore the overall goals of the project must be clearly defined and the role that mechanical scanning sonar plays in achieving the stated goals needs to be thought through before field work begins.

Capabilities of Mechanical Scanning Sonar

Capable of capturing complex three dimensional shapes

Properly and accurately documenting complex shapes and curves underwater has long been a problematic and inefficient process for nautical archaeologists. In this roll, mechanical scanning sonar performs exceptionally. With the density of the sonar data gathered by the unit, complex shapes can now be represented by thousands of points of data where traditional techniques would have attempted to record the same shape with only a handful of measurements.

Ease of deployment with or without diver

With proper training the deployment and use of the mechanical scanning sonar unit is fairly straight forward. The software interfaces are clear and easily understood and the handling of the unit itself is also quite simple. Whether you are deploying the system with diver assistance or directly from a vessel, as long as it comes to rest on a stable surface prior to starting the data capture it will gather useful information.

Equally effective in low visibility environments

When compared to other three dimensional documentation techniques (laser scanners, photogrammetry) the fact that mechanical scanning sonar employs sounds as the medium for measurement allows this system to be as effective in low visibility environments as it is in a clear water situation. This fact alone ensures that this technology will fill an important role in the archaeology tool box of submerged cultural resource managers and researchers.

Individual scans can be assembled into a comprehensive 3D site plan with relative ease and accuracy

The ability to assemble individual scans into comprehensive point clouds of an entire site is also a very valuable and powerful research advantage of mechanical scanning sonar. By capturing scans from several different locations around a feature it is possible to gather sufficient information to gain a much clearer understanding of a site in a relatively short amount of time (Figure 4). And with the use of registration marks and proper post-processing techniques the accuracy of these point clouds can also prove very valuable. Though the scanner cannot pick up surface details and very tight timber joints it can provide an accurately shaped "framework" for other measurements and observations to be applied to.

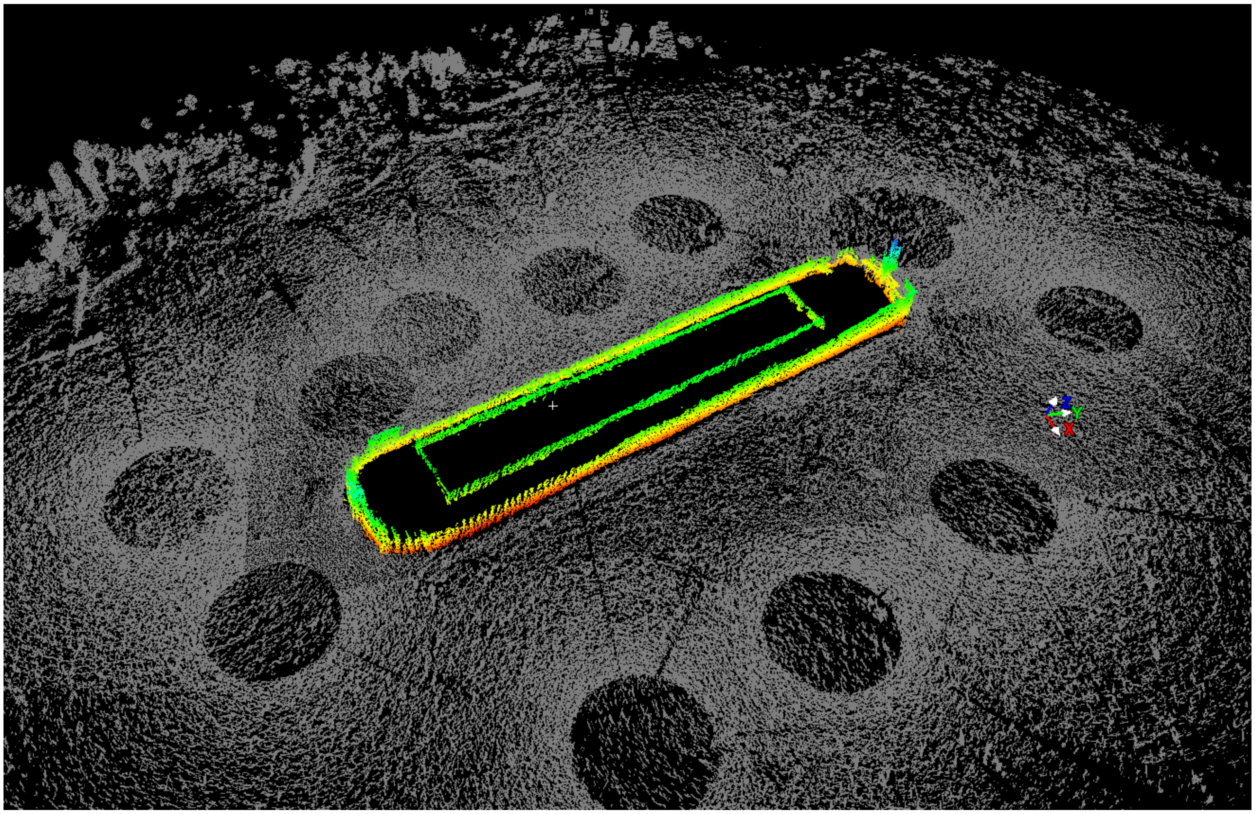
Figure 4: Composite point cloud of the South Bay Canal Boat (LCMM Collection)

Limitations of Mechanical Scanning Sonar

Lack of surface detail
While the mechanical scanning sonar unit has great ability to capture overall shapes and sizes of timbers and features, one area where it currently lacks ability is in capturing surface detail, fasteners, and timber scarfs and joints. These details are still best captured by direct observation and documentation by an archaeological diver.

Expense
One facet of the mechanical scanning sonar technology that archaeologist must keep in mind is the high cost of purchasing or renting this piece of equipment. While the price and availability of this technology seems to be becoming more accessible, it is still a major consideration when determining the best application of limited research funds to a project. It also increases the importance of pre-project planning and infrastructure placement to allow the most efficient capture of data in the shortest amount of time.

Post-processing
In addition to the cost of obtaining the unit itself, project planners must also keep in mind the cost of post-processing the data if they are not willing to invest in training themselves or a crew member in the point cloud stitching process and software. If the post processing of data is outsourced, project planners must also take into consideration the scheduling of that task and how it will affect overall project timelines. The amount of time needed to complete the post-processing will depend greatly on the complexity of the site being documented as well as the number of point clouds that need to be assembled. More scans and

the more complex the site the longer it will take to post-process and therefore the more expense required for this effort.

Development of a research design that capitalizes on the technologies strengths and minimizes its limitations.

A thorough understanding of this technologies strengths and limitations suggests that employment of this piece of equipment should fall into one of two types of field operations: Reconnaissance or Documentation.

Reconnaissance

Mechanical Scanning Sonar has great potential for site reconnaissance and gaining a better understanding of a newly discovered site. In site locations where in-water visibility is low and target verification with divers or ROV is not feasible, the deployment of a mechanical scanning sonar unit can provide rapid acquisition of basic site data in a short amount of time. The sonar data can aid in determining site orientation, delineation and boundaries, preliminary identification of site components or features, and preliminary determinations of significance. This information can then be used to plan a more detailed documentation plan for future study of the site, if needed.

Documentation

In some cases the mechanical scanning sonar system can be employed as one of the principal tools for the documentation of a submerged cultural resource. This will prove particularly valuable in low visibility environments where traditional diver oriented documentation techniques are not practical. Mechanical scanning sonar also offers a documentation team a fast accurate method for capturing the complex shapes that are often encountered on submerged cultural resource sites and shipwrecks in particular. This data set can greatly enhance the accuracy and efficiency of other, more traditional recording techniques that are carried out in addition to the sonar data by giving the research team a frame work on which to apply additional measurements and observations.

METHODICAL BEST PRACTICES

The following is a list of recommended procedures and instruction for gathering the maximum amount of information in the most efficient manner possible. These methods have been developed through technical training, consultation with industry experts, and hand on experience with mechanical scanning sonar. This list should not be considered absolute and some level of adaptation to a particular site and its setting should be expected.

Site preparation

When planning to capture mechanical scanning sonar data of a site, carrying out some initial site preparation can facilitate the efficiency with which the data is captured. The process of site preparation is particularly valuable when the mechanical scanning sonar will be used as one of the primary documentation tools for the site. Researchers carrying out a reconnaissance level site exploration will need to determine which of these steps is necessary, or practical, given their targets particular setting and their overall project goals.

Site Delineation

Gaining an understanding of the site to be documented with the mechanical scanning sonar is of principal importance in planning a project for this technology. Therefore, a thorough understanding of the outer limits of the site are one of the first pieces of information that must factor into project planning. This information can be acquired in a number of ways including diver Reconnaissance, preliminary sonar scanning, use of an ROV or any combination of these.

Once the extent of the site is fully understood then researchers can develop a Scan Plan that will gather the most useful information in the most efficient manner. Knowing the boundaries of the site before the start of an intensive scanning program will allow researchers to pinpoint the locations from which the most advantageous and informative scans can be taken. They can also insure that these scan locations will provide sufficient overlap which will in turn facilitate the assembly of individual scans into a composite point cloud for an entire site (Figure 5).

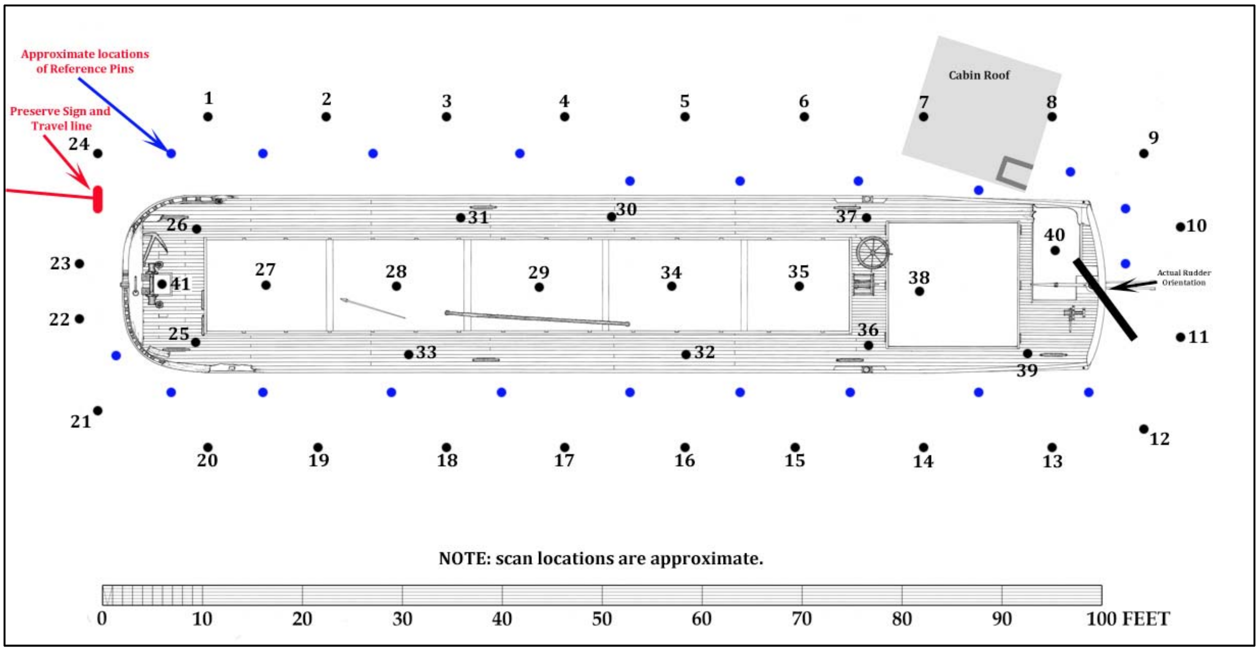

Figure 5: Example of a Scan Plan created for the Sloop Island Canal Boat Documentation Project (LCMM Collection)

Registration Marks

The use of registration marks should be considered standard procedure whenever applicable. Registration marks, small targets of, know dimension, located between scan locations that show up in both scans, provide a common point of reference between scan locations that greatly aid in the assembly and accuracy of composite point clouds that are created during the post-processing phase of work.

While it is possible to create composite point clouds without the use of registration marks their usefulness is obvious. In fact, during discussions with technicians from Teledyne Blueview it was recommended that two registration marks, each unique in shape, be placed between scan locations to further enhance the efficiencies of point cloud assembly. Of course, the proper placement of registration marks may not be possible depending on local environmental conditions. They may also not be necessary if the goal of the scanning operation is reconnaissance or initial exploration of a new site.

Deployment of the scanning unit

While the possibility of an ROV mounted Scanning sonar system is under development, there are currently two main methods for deploying the mechanical scanning sonar unit: 1. the use of divers to position the unit on the bottom 2. lowering the scanning unit to the bottom by rope from a surface platform without the use of divers. Both of these options are perfectly viable depending on the site condition, size of resource, in-water visibility, depth of water, and a host of other factors. The following is a discussion of the advantages and limitations of each of these two deployment methods.

Diver aided deployment

Diver aided deployment of the mechanical scanning sonar unit has a number of advantages and challenges associated with it.

Advantages:

- Employing a diver to position the scanning unit around/on a particular site allows researchers to precisely pin point each preplanned scan location.
- When positioned by a diver the researchers are assured that the scanner is positioned facing the site. This allows the capture of only necessary data (180 degree scan vs. 360 degree scan) which in turn allows for shorter scan times.
- When a diver is employed to position the scanner at preplanned locations, researchers will be confident that any registration marks placed between scan locations will appear in the "field of vision" of the scanning unit, thereby facilitating the post processing of the sonar data.
- A diver is able to carefully manipulate and position the scanner tripod on uneven surfaces or around obstructions on the bottom, this can prove very challenging when deploying from a vessel without a diver.

Limitations:

- Deployment of the scanning unit by divers is labor intensive and may not be practical given project logistics and funding.
- Diver deployment may not be practical given local water conditions (for example: limited/no visibility).

Surface deployment

Currently the only practical alternative to diver deployment of the sonar unit is deployment directly from the surface by lowering the unit with a line or hoist. Like diver deployment it has both advantages and limitations.

Advantages

- Ease of operation. With a basic lifting arm, or gantry, the scanning unit can be safely and easily lowered to the site for scanning by a small crew
- Less labor intensive. Without employing divers this technique requires a smaller and less expensive crew to carry out a survey
- Can operate on a smaller platform without the congestion that multiple divers and their gear can create on a research vessel.

- Most advantageous for recon operations of a site or where the project goals only require a basic understanding of the site rather than very detailed documentation of surface details etc.

Limitations

- When deployed from the surface it is often hard to control exactly where the unit lands with any precision.
- It is often unclear if the scanner is upright until the scan has started and the initial data is collected.
- Lack of clarity about the orientation of the scanner once settled on the bottom often requires the capture of 360 degree scans to ensure that the target is within the scan area. This can lead to longer scan times at each location.
- Very difficult to get a proper set on uneven bottoms. Also difficult to place on, or in, a wreck site without the device tipping over or the potential for entanglement.
- With boat deployment it can be difficult to properly place registration marks that will appear in multiple scans.

ROV Deployment

One option for deployment of the scanning unit that has not discussed in detail here is the possibility of mounting the scanning unit on a Remotely Operated Vehicle (ROV). This is an option that is currently being developed and studied. With the current technology it is possible to mount the scanning unit on a ROV however the unit must settle onto the bottom and remain still during the entire scanning process. Future development may allow for the ROV to "hover" while the scanning takes place. Keeping up to date on the continuing evolution of this technology, like ROV mounting, will open up new research opportunities for the cultural resource manager in the future.

Post Processing

The post-processing of data sets collected with a mechanical scanning sonar is a very important part of the process and requires specialized skills in the manipulation of the point clouds in order to extract, and present, the most valuable data from them.

If a research team has the software needed and the expertise to use it properly, the most cost effective option is to perform your own data processing in-house. This saves the considerable expense of paying a specialist to post-process your data as well as giving you the flexibility to produce the final work products that are most valuable to your research team and design. However, it should be noted that the software packages for processing and stitching together multiple point clouds are expensive and quite complicated. Proper training and experience with the software packages will require a significant investment, both in money and time, before you can be assured that you are getting the maximum use of the data sets.

The other option for post processing of data is to employ a specialist to carry out this task. This option can be costly in terms of the salary that specialists charge but do not require the acquisition of the expensive software or training to be able to handle this task in house. If a contractor is used for the post processing of project data it is very important that you have open and clear communications with the contractor about the exact types of information you are hoping to extract from the combined data and special "views" that should be produced.

It is also very important to provide your data processor with as much information about the project as possible. This information should include:

- Goals of the project
- General environmental site information
    - Water temperature (at depth)
    - Water depth
    - Presence/absence of current
    - Bottom sediment type
- Number of scan locations
- Types of scans captured at each location
- Detailed information about any registration marks used and their locations
- Deployment method used
- Any other information that will define the "context" of the project for the post-processing team.

Retention of .son data

In the post processing effort it is important that not only the .xyz (point cloud) files be presented for post-processing but also the raw sonar data that is collected in .son format. This raw data will allow the data processor to refine the point clouds and it often contains minute details that are not readily visible on the data rich point cloud images. The .son files are basically the individual "slices" of sonar data that are then assembled into the more comprehensive point clouds. This raw data has not been "filtered" by the point cloud generating software and can therefore be adjusted to provide the maximum amount of accurate information.

Post-processing Products

Composite Point Cloud

Perhaps the most useful, and informative, product of post-processing data collected by a mechanical scanning sonar system is the composite point cloud that presents the site in its entirety. While individual scan locations can contain a huge amount of data and information the fact that the separate scans can be stitched together to form an image that presents an entire site is extremely powerful. By using point cloud viewing software (like BlueViewer) a researcher is able to manipulate the composite point cloud to view it from any angle. There is also the ability to take measurements from a composite point cloud. This allows researchers to examine a site in a way that may not be possible even with divers. In many cases limited in-water visibility means that divers can only visualize the portion of the site directly in front of them, where the composite point cloud allows them to gain a better understanding of the site in its entirety.

Once assembled into a composite point cloud this combined data can be further processed to create informative images of smaller sections of a site. For instance, the composite point cloud of an entire shipwreck can be "sliced" transversely to provide researchers with a cross-sectional view of the vessel hull (Figure 6). This ability also allows researchers to highlight particular construction features by producing detailed images of only a portion of a site for closer examination.

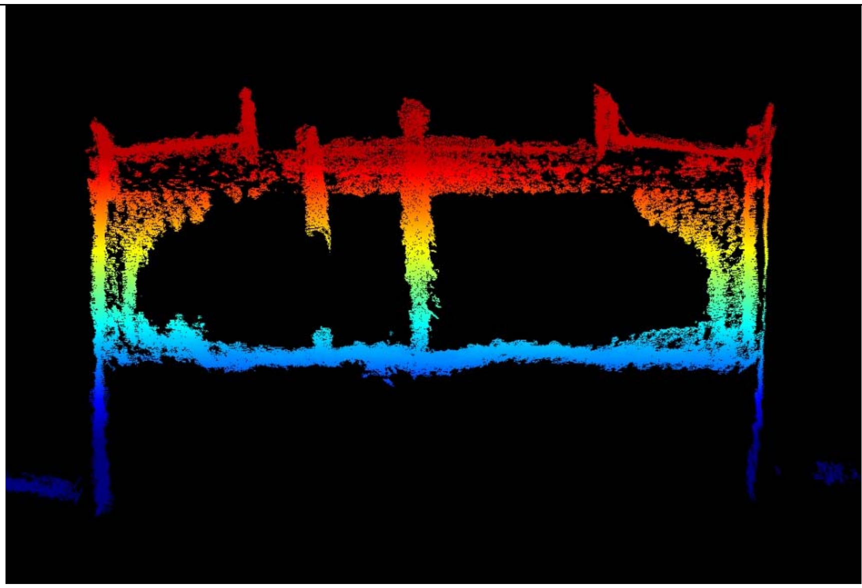

Figure 6: Cross sectional view of the Sloop Island Canal Boat (LCMM Collection)

Movies

Another valuable product of post-processing is the ability to make short movies of a "fly through" of the site. This option allows other researchers and interested public to get a good understanding of a site without having to use specialized software or to handle the actual data from the project. As an example of this work product see this youtube video of the Sloop Island Canal boat that was produced by Teledyne Blueview using data captured by LCMM researchers: https://youtu.be/CIzLQ_8L5g4

Public Outreach

All of these products of post processing provide powerful opportunities for researchers, but their value extends well beyond that. When used as interpretive materials for the interested public the post processed images and movies offer a compelling way to share information with the public. As the products are digital they can be easily shared through hands on displays with tablets or computers allowing visitors to manipulate the point clouds themselves. It also makes the information easy to share via the internet. This is particularly true of the fly-through movies that can be created from composite point cloud files. Public interpretation of archaeological data should always be a component of any archaeological research design and the post-processed data from a mechanical scanning sonar survey is a particularly effective way to accomplish this goal.

CASE STUDIES

SLOOP ISLAND CANAL BOAT

The mechanical scanning sonar documentation of the Sloop Island Canal Boat took place on Lake Champlain in the summer of 2012. The goals of this project were document the late nineteenth-century canal boat with mechanical scanning sonar and compare the results with the traditional archaeological data that had been collected by archaeological divers in 2001-2002 in order to gain a better understanding of this technologies abilities. Researchers from the Lake Champlain Maritime Museum employed a Teledyne BlueView BV-5000/2250 sonar unit and recorded scans from 41 locations on, in, and around the 97 foot long, 17 foot wide, canal boat that had come to rest in nearly 90 feet of cold fresh water.

For this operation LCMM deployed the scanning unit with diver assistance and considerable infrastructure in place. All scan locations were predetermined and low tech registration marks were deployed between scan points. This level of infrastructure and preplanning allowed the LCMM team to capture all scans over a two day time period with another day employed for infrastructure establishment and breakdown.

The post-processed results of the Sloop Island Survey, and their comparison with the traditional data set collected earlier, were extremely informative about the capabilities and limitations of the sonar system and also pointed out some flaws in the traditional data set previously collected by divers. The mechanical scanning sonar was extremely effective at accurately documenting complex curves and shapes, this is most obvious in a comparison of the plan view site drawing based on diver measurements with that recorded by the BlueView scanner (Figure 8).

For additional information see: http://www.lcmm.org/mri/projects/scanning-sonar-sloop-island.htm

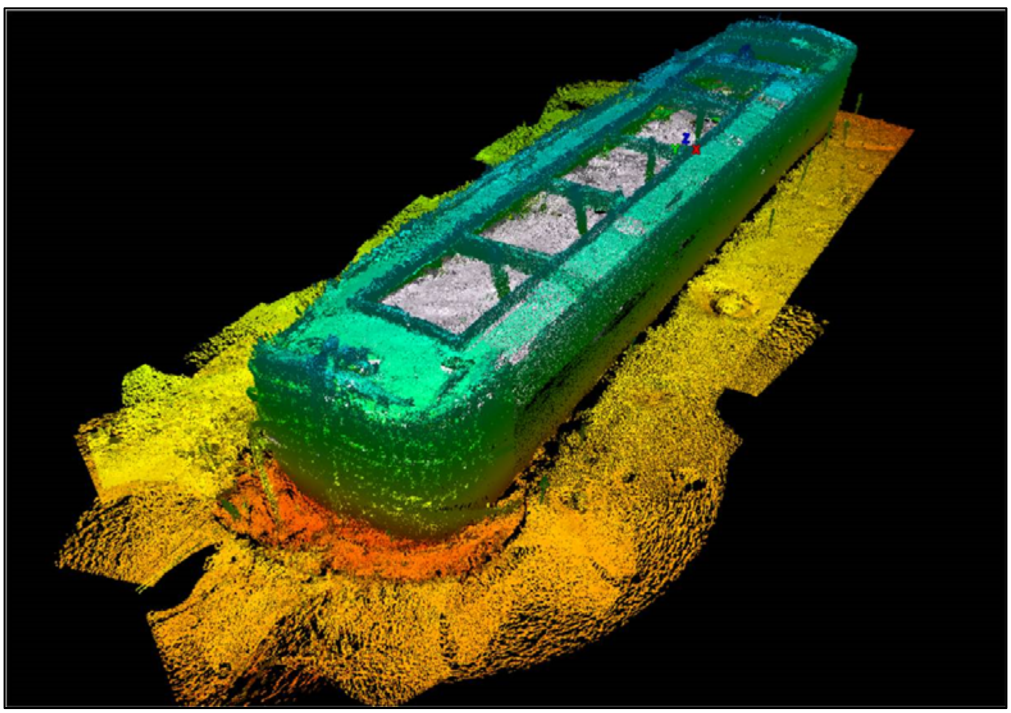

Figure 7: Composite point cloud of the Sloop Island Canal Boat (LCMM Collection)

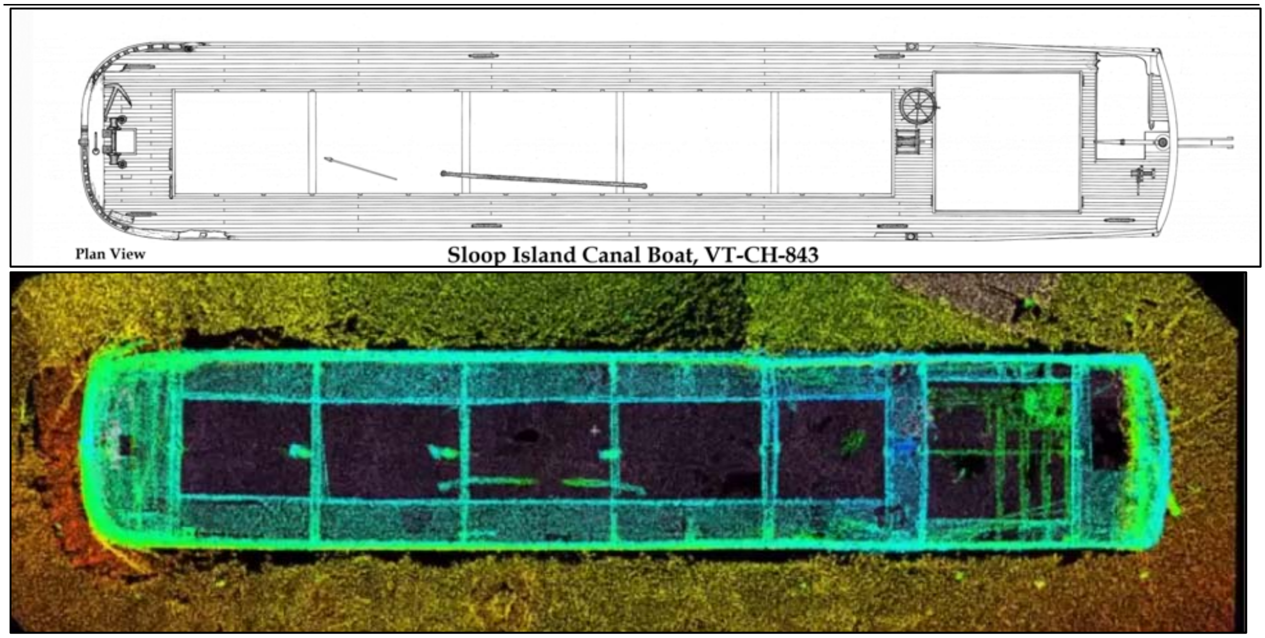

Figure 8: Comparison of the plan drawing of the Sloop Island Canal Boat and that generated by the mechanical scanning sonar (LCMM Collection)

SOUTH BAY CANAL BOAT SURVEY

During the summer of 2013 LCMM researchers employed a mechanical scanning sonar to gain a better understanding of another canal boat shipwreck located at the very southern end of Lake Champlain in South Bay. This vessel, resting in 16 feet of water, had been previously located during a side scan survey of the area (2003) but due to zero visibility conditions no diver verification had been attempted. Supported by a grant from the Fund for South Lake Champlain the LCMM archaeologists deployed the BV-5000/1350 sonar unit to carry out an initial reconnaissance and base line documentation of this site.

Working off of a shallow drafted pontoon boat LCMM researched deployed the scanning unit from the surface by lowering it with a rope and lifting arm. Additionally, improvised registration marks were deployed around the site and their locations were indicated on the surface through the use of a float attached to each (this also facilitated their recovery when scanning was completed). Scan points were located between each pair of registration marks. This system proved to be efficient and effective though some difficulty was encountered in attempts to place the scanner on the deck of the vessel and in its cargo hold. Without divers to aid the placement of the tripod in these areas it proved difficult to deploy the scanner without it tipping over. This led to a number of wasted scans with no research value.

Overall this project demonstrated the benefits and limitations of surface deployment of a mechanical scanning sonar unit while capturing sufficient data to give researchers a much better understanding of this site despite the zero visibility conditions.

For additional information: http://www.lcmm.org/mri/mri.htm

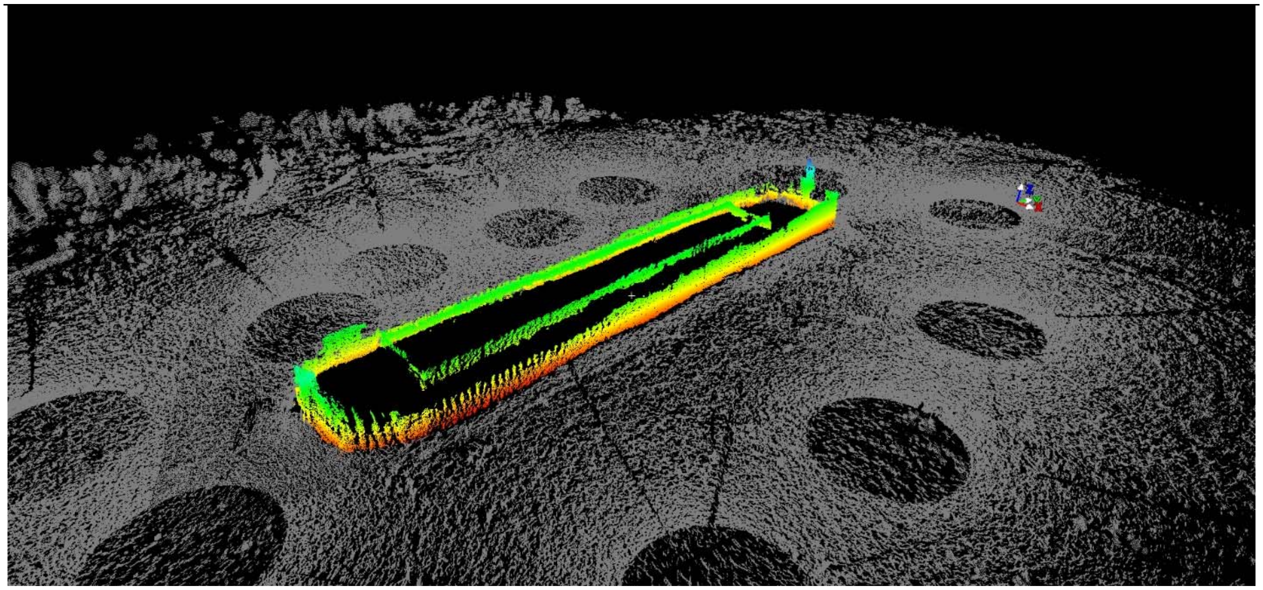

Figure 9: Composite point cloud of the South Bay Canal Boat (LCMM Collection)

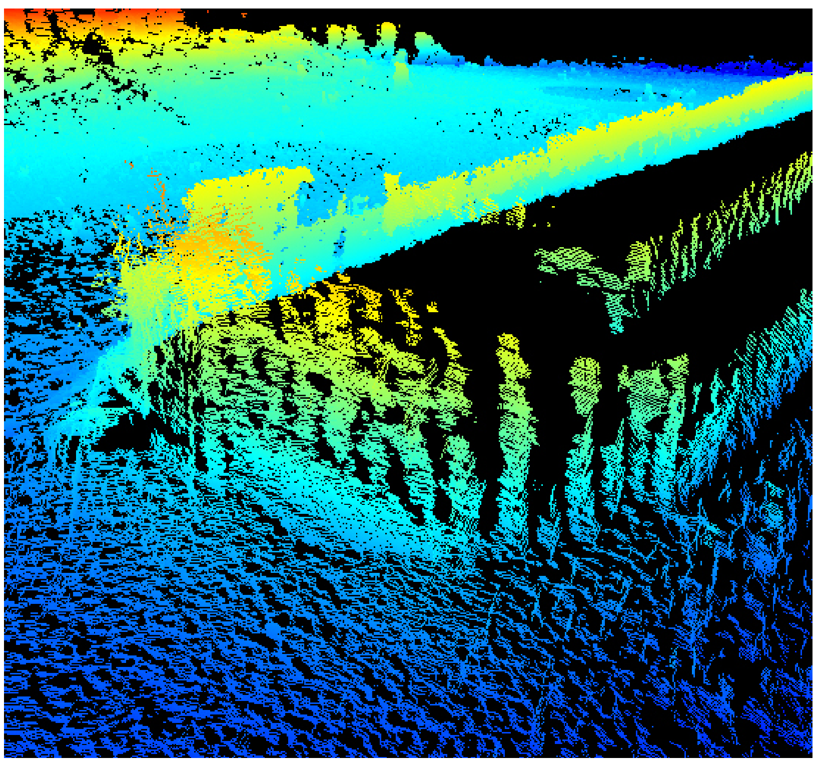

Figure 10: Close up of the bow section of the South Bay Canal Boat showing the exposed framing (LCMM Collection)

AJ GODDARD

The remains of *AJ Goddard*, a Klondike gold rush steamer (built 1898, sunk 1901) sunk in Lake Laberge Alaska, were documented in 2009 and 2010 and included the use of a BlueView BV-5000. This project documented the steamship, which rests in murky water, with a mix of traditional techniques and mechanical scanning sonar. In this case the scanning unit was positioned around and on the wreck in 22 different locations. Researchers working on the Goddard found the sonar data to be particularly useful in gaining an overall understanding of the site and for documenting the interior structures of the small steamer which are inaccessible to divers. This project was the first nautical archaeological project to employ the BlueView BV-5000 unit for archaeological documentation purposes.

For additional information:
http://www.tc.gov.yk.ca/publications/The_AJ_Goddard_Reconstruction_2012.pdf

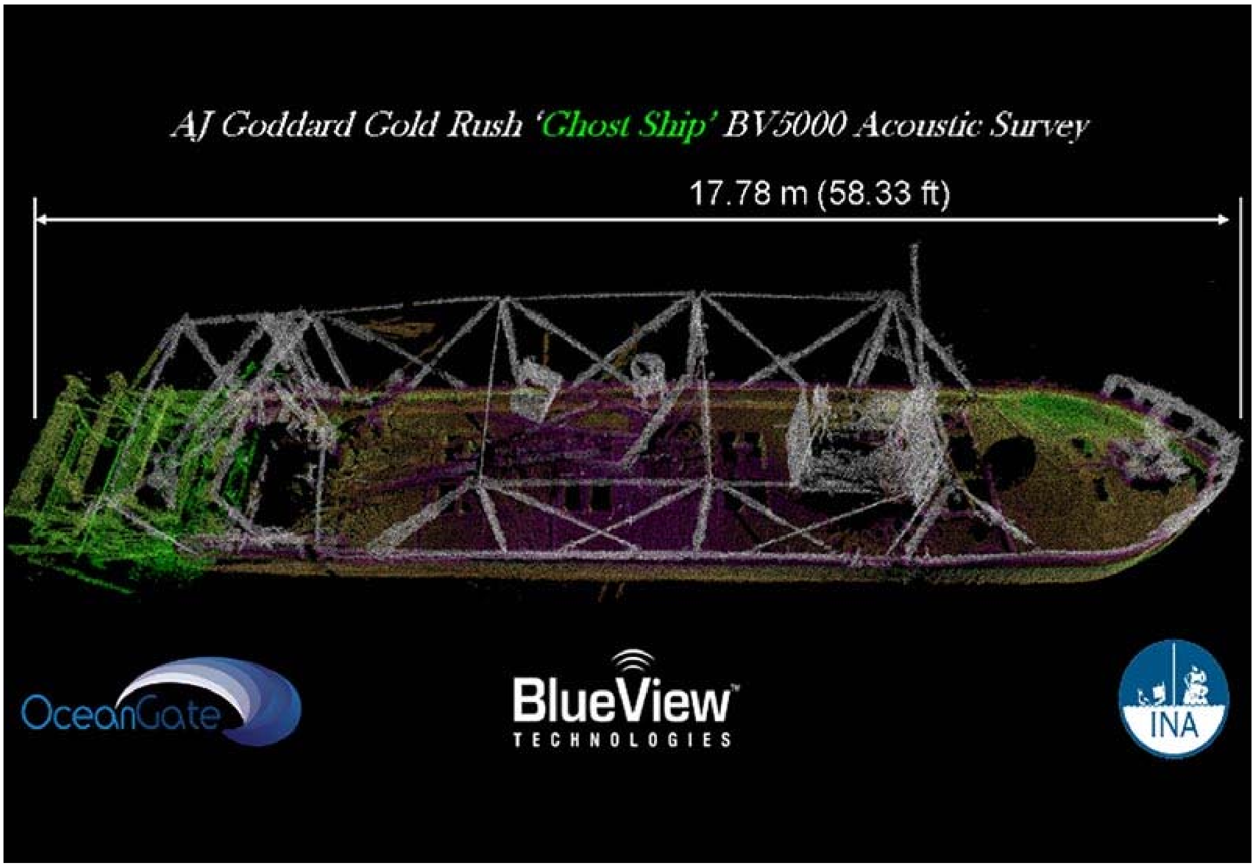

Figure 11: Composite point cloud of the *AJ Goddard* (OceanGate)

USS HATTERAS

The *USS Hatteras* was the only Union vessel sunk by enemy fire in the Gulf of Mexico during the American Civil War. Over time the remains of this vessel were broken up by storms and much of the structure was covered by shifting sands. Storms in 2012 uncovered some portions of the site that had not been previously explored and a team from NOAA took the opportunity to document the newly exposed portions using the BlueView scanning sonar system. The wreck lies in 57 feet of water and the scanning unit was deployed from the research vessel without the assistance of divers.

The 2012 scanning program of the *USS Hatteras* wreck site gave NOAA researchers a chance to document previously unknown portions of the wreck site. The composite point cloud that was created from the multiple scan locations revealed that the a large portion of one paddle wheel is extant on site and that portions of the ship's stern and rudder are emerging from the sand.

For additional information: http://sanctuaries.noaa.gov/news/press/2013/pr011113.html

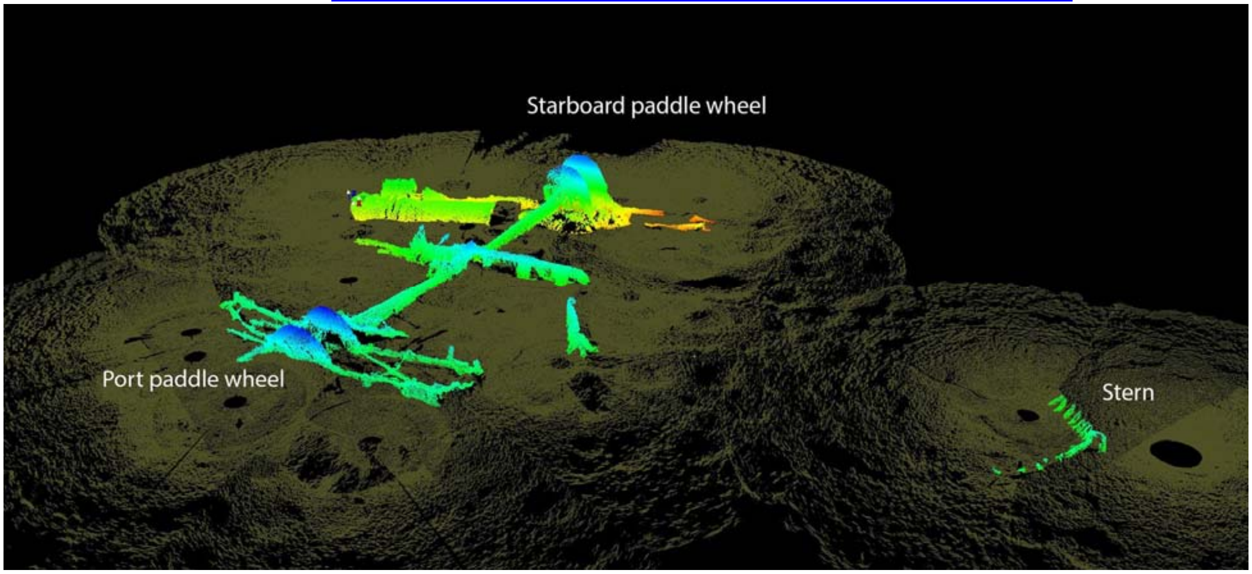

Figure 12: Composite point cloud show the exposed portions of the *USS Hatteras* (NOAA)

CONCLUSIONS

The emergence of mechanical scanning sonar has added powerful new documentation option to the "tool box" of the nautical archaeologist. When used for the proper application and with realistic goals about the nature of the final product it will produce, this sonar technology can increase the efficiency and accuracy of submerged cultural resource documentation. At this point in its development, mechanical scanning sonar will not replace the need for traditional documentation but can be used to make that process faster, more accurate, and more efficient. A combination of the two documentation techniques will produce the level of detail and accuracy that neither can produce on their own.

One of this sonar's strongest attributes is that it can achieve this level of detailed documentation even in water conditions that would make traditional recording extremely difficult, potentially inaccurate, and dangerous. Low, or zero, visibility environments are one of the most challenging dive situations in which an underwater archaeologist can work. Deployment of a mechanical scanning sonar in a situation such as this offers great potential for capturing accurate data without putting divers at risk.

In order to achieve the maximum efficiency and effectiveness of this emerging technology, it is necessary to have a full understanding of the strengths and weakness of mechanical scanning sonar. When used as a starting point for further research, this manual has provided a level of knowledge and best practice procedures that will allow researchers to determine if this is a technology that could aid in the achievement of their project goals.

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