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3D visualisation of historic and environmentally significant shipwrecks
the development of occlusion objects, Locoramps and digital cinematography

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Chris Rowland

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3D Visualisation of Historic and Environmentally Significant Shipwrecks

The Development of Occlusion objects, Locoramps and Digital Cinematography

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Submitted in fulfilment of the requirement for the degree of Doctor of Philosophy

University of Dundee
Duncan of Jordanstone College of Art & Design

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Abstract

This thesis explores the hypothesis that current industry standard methods used to visualise environmentally hazardous or historically significant shipwrecks can be improved by adopting a number of new, aesthetically considered, methods.

The thesis describes the development of occlusion objects, locoramps and the use of digital cinematography, as methods that the author proposes to improve the 3D visualisation of point cloud data from multibeam sonar. Case studies were selected as the basis for experimentation; they include HMS Royal Oak in Orkney and SS Richard Montgomery in the Thames Estuary.

The author collaborated with a multi-disciplinary team of forensic maritime archaeologists, marine surveyors and salvage experts to gain access to unique shipwreck sites and the high resolution sonar data gathered from them. Through experimentation with the data, occlusion objects, locally oriented colour ramps (locoramps) and improved depth cueing through digital cinematography were developed and applied in 3D visualisations of the case study wrecks. A real-time application WreckSight was created to exploit the new methods.

The resulting 3D visualisations of the wrecks were evaluated by a number of target audience groups by means of an interactive questionnaire that allows a direct comparison of data presented using the new methods with traditional display methods. Analysis of the resulting data shows a statistical significance that supports the hypothesis. The author proposes that the new methods constitute new knowledge in the 3D visualisation of multibeam sonar data of shipwrecks.
# Glossary

Description of terms and abbreviations:

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
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<tbody>
<tr>
<td>AHRC</td>
<td>Arts and Humanities Research Council</td>
</tr>
<tr>
<td>ADU</td>
<td>Archaeological Diving Unit: The marine archaeology research team based at St Andrews University</td>
</tr>
<tr>
<td>ADUS</td>
<td>Advanced Underwater Surveys Ltd</td>
</tr>
<tr>
<td>Bathymetry</td>
<td>Measurement of the depth of ocean floors</td>
</tr>
<tr>
<td>Beam</td>
<td>Width measurement of a ship</td>
</tr>
<tr>
<td>Fledermaus</td>
<td>Commercial bathymetric data visualisation software produced by IVS 3D</td>
</tr>
<tr>
<td>Geomagic</td>
<td>Industrial design software used for reverse engineering and point cloud editing from laser scanners</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic information system</td>
</tr>
<tr>
<td>HMS</td>
<td>Her Majesty’s Ship: Naming convention for British Navy vessels</td>
</tr>
<tr>
<td>ISHAPS</td>
<td>Independent Sonar Head Attitude and Positioning System: A sonar head deployment system developed by ADU</td>
</tr>
<tr>
<td>Locoramps</td>
<td>Locally Oriented Colour Ramps: Novel method for colouring sectioned point cloud data to improve the visibility of fine detail</td>
</tr>
<tr>
<td>Maya</td>
<td>Commercial 3D modelling and animation software from Autodesk</td>
</tr>
<tr>
<td>MCA</td>
<td>Maritime and Coastguard Agency (UK)</td>
</tr>
<tr>
<td>MOD</td>
<td>Ministry of Defence (UK)</td>
</tr>
<tr>
<td>Multibeam Sonar</td>
<td>Sonar that produces a swath of sound beams rather than a single Beam</td>
</tr>
<tr>
<td>NATO</td>
<td>North Atlantic Treaty Organisation</td>
</tr>
<tr>
<td>NSRC</td>
<td>NATO Submarine Rescue Service</td>
</tr>
<tr>
<td>Occlusion Object</td>
<td>Novel method to prevent point cloud data from being visible in the gaps between points</td>
</tr>
<tr>
<td>ODM</td>
<td>Optical Distance Measurement</td>
</tr>
<tr>
<td>Polygon</td>
<td>Computer graphics modelling element consisting of points, edges and faces</td>
</tr>
<tr>
<td>Point cloud</td>
<td>A collection of xyz co-ordinates produced by laser or sonar scanning devices</td>
</tr>
<tr>
<td><strong>Render</strong></td>
<td>The process of drawing an image in 3D computer graphics software</td>
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<td>------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>RGB</strong></td>
<td>Red, Green, Blue: A colour system used by computer graphics software</td>
</tr>
<tr>
<td><strong>RINEX</strong></td>
<td>Receiver Independent Exchange format: A software interchange format for distributing raw satellite navigation system data</td>
</tr>
<tr>
<td><strong>ROV</strong></td>
<td>Remotely Operated Vehicle: Unmanned submersible vehicle used for underwater surveying</td>
</tr>
<tr>
<td><strong>RTK</strong></td>
<td>Real Time Kinematics: Method for tracking the position of underwater vessels (e.g. ROVs)</td>
</tr>
<tr>
<td><strong>Side-Scan</strong></td>
<td>Underwater acoustic imaging device</td>
</tr>
<tr>
<td><strong>SONAR</strong></td>
<td>Sound Navigation and Ranging: Navigation system that uses acoustic signals to detect objects and movement</td>
</tr>
<tr>
<td><strong>SS</strong></td>
<td>Prefix used in the naming convention for non-military Steam Ships</td>
</tr>
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Declaration

This thesis is the work of Chris Rowland and the author is solely responsible for the contents. The contents of this thesis have not been submitted for any other higher degree.

........................................

Chris Rowland
MA, BA (Hons)
Acknowledgements

I recall some very good advice I was given when I moved into academia:

“Don’t get involved with academic research unless you want to jump out of bed to do it!”

I took this advice and combined two of my passions: exploring shipwrecks and 3D animation. The result has been a challenging journey through the depths of shipwreck visualisation. This PhD thesis is the result.

I would like to acknowledge all those who have supported the journey. My supervisors, Professor Nigel Johnson and Dr Steve Parkes have encouraged, prodded and scolded me into sustaining the investigation. They have offered practical advice when I needed it and kept me on track when deadlines were evading me. For this, I offer my sincere thanks.

The excellent shipwreck data provided by my colleagues at ADUS, Martin Dean and Mark Lawrence, provided a platform from which to experiment. Our continued collaboration is a source of inspiration and for this I thank them.

My final thought is for the family support I have received. My wife Janice has constantly encouraged me, tolerating my research mess as it has gradually enveloped our home. Our sons, Sam and Jacob have grown up through this process and I thank them all for their occasional interest but unflagging love and support, without which I could not have reached the end of the journey.
Preface

My interest in the mystery of shipwrecks was first truly awakened through my training and subsequent experience in recreational scuba diving. The first time a wreck appears from the gloom, as you descend into the ocean, is an awe inspiring event. From the surface it is impossible to imagine the feeling of floating weightless over decks littered with debris from some catastrophic event that caused the vessel to fall to the seabed.

As a diver, one occupies a 3 dimensional space in the water column, free to tumble and glide in any direction exploring an underwater environment that most humans will never see. This tacit knowledge gained by diving has given me an opportunity to portray these invisible monuments to human industry and endeavor, reclaimed by nature, in a manner that hopes to communicate the significance to our maritime culture.

Prior to entering academia, my background was originally founded in creative art practice. I studied Fine Art, specialising in film, video and sound at Maidstone College of Art under the guidance of the “Father of British Video Art”, David Hall. This was followed by a Masters degree at Duncan of Jordanstone College of Art, where I took my first tentative steps in 3D modeling and animation.

This led to a career in television post production, applying my creative practice to 3D animation work in broadcast TV, advertising and communication. This period saw the rise of 3D technologies from a specialist, expensive luxury in production to a necessary part of the industry. The emerging games industry was a key force in expanding the demand for 3D computer graphics. Graphics technology rose to the
challenge, providing ever faster hardware to cope with the creative demands of the industry.

Today, we accept 3D imagery as part of our everyday experience of culture. The same techniques are used to create blockbuster films as are deployed to design the next generation mobile phone. It is in this environment that 3D animation can be creatively applied to visualise ideas and solve problems in almost any subject area.

It didn’t take a great leap of faith to connect my passion for diving on shipwrecks with my professional experience in 3D animation and visualisation, therefore sowing the seeds of this doctoral study. My first steps in this area led me to Orkney and the wrecks of Scapa Flow, a Mecca for wreck divers. The German High Seas Fleet was interned here at the end of WWI, eventually scuttled by their commanding officer, leaving some of the most interesting military wrecks on the seabed. Diving these wrecks introduced me to the common practice of using illustrations and artists’ impressions of the wrecks to plan the diving. My 3D sensibilities were disappointed with the fixed and often inaccurate views these images provided. The challenge to improve the situation was born.

I tracked down kindred spirits Martin Dean and Mark Lawrence at the Archaeological Diving Unit (ADU) based at St Andrews University. At the time, they were pioneering the use of multibeam sonar to accurately record historic shipwreck sites around the UK. Seeing their early results inspired me to get involved and the Advanced Underwater Surveys (ADUS) research partnership was established. My role was to research methods to improve the way the data was visualised in 3D. This opportunity, combined with my interest in recreational diving, lies at the core of this doctoral study.
1. Introduction

"Society is underpinned by its understanding of history, and this in turn is profoundly influenced by the survival of the physical artifacts that embody much of our cultural heritage buildings, landscapes, works of art, books, and so on. These constitute a legacy left to us by our forebears, which we in turn have a duty to pass on to our descendants."

House of Lords Select Committee, Science and Technology (HoL 2006)

Britain has a strong maritime history that directly or indirectly touches the lives of many people, for example through trade, seafaring and transportation. The level of national interest in this area was clearly evidenced with the overwhelming support and financial pledges to restore the Cutty Sark after the fire damage in 2007.

"The recent destruction wreaked on the Cutty Sark, and the numerous outpourings of support, both in the UK and internationally, to restore it to its former glory as soon as possible, are eloquent testimony to how we treasure such rare and important historical artifacts. The national sense of the value of these assets shows that adequate public resource should be devoted to their preservation and utilization."

Philip Esler, AHRC Chief Executive, 2007. (Esler 2007)

The Cutty Sark is a highly visible, piece of national heritage. However, the remains of many equally important historic ships lie beyond the public gaze.
1.1 Maritime Heritage Sites

There are 62 maritime heritage sites around the UK coast which are designated as historically and environmentally significant under the Protection of Wrecks Act (1973). The wrecks are managed on behalf of Her Majesty’s Government by English Heritage, Cadw¹ and Historic Scotland. The wrecks range from the remains the Stirling Castle, a flagship of Samuel Pepys’ navy, (Curtis, J, 2009) which sank in 1703 on Goodwin Sands in Kent, to the remains of the WWI German High Seas Fleet scuttled at Scapa Flow, Orkney in 1919. (Van der Vat, D, 2007)

Designated sites are identified as being likely to contain the remains of a vessel, or its contents, which are of historical, artistic or archaeological importance. Due to the fact that all of these sites are submerged, they are effectively invisible to the general public and the majority of specialist researchers (hydrographers, historians, artists etc).

1.2 Marine Salvage

Interest in shipwreck sites is not limited to their cultural or historic significance. Environmental factors are also important. Marine salvage is carried out when a shipwreck may be a danger to shipping or the environment. When hazardous cargo (e.g. munitions or oil) create an environmental threat, salvage teams are engaged to assess the risk then carry out procedures to minimize the impact. This investigation examines the requirement for high resolution, accurate visualisation in the marine salvage industry and proposes new methods to improve the visualisation of multi-beam sonar data in this field.

¹ Cadw (English: to keep) is the historic environment service of the Welsh Assembly Government
1.3 Collecting Multibeam Sonar Data

The collection of multibeam sonar data is a complicated process. It requires the mobilisation of a collaborative team of technical experts with the added complexity of often unpredictable environmental factors. A survey vessel, laden with complex technology must be skippered accurately over the target wreck site with changes in position, wind speed, tide and weather corrected by up to fourteen communications satellites tracking from space. In its simplest form, the data is represented as Cartesian co-ordinates \((x,y,z)\) (Figure 1.1) where \(x\) and \(y\) relate to global positioning and \(z\) relates to depth below sea level. When these co-ordinates are represented in 3D, they appear as groups of small dots collectively referred to as point clouds.

![Figure 1.1 Cartesian axes](image)

Should the survey data collection be successful, the resulting datasets are then analysed by maritime archaeologists to establish the condition of the shipwreck. However, current industry standard software (e.g. Fledermaus, Interactive Visualisation Systems 3D) developed to display the data for forensic analysis uses a \textit{default} aesthetic, usually based on depth being colour coded with bands of equally spaced colour (Figure 1.2). This can bear little resemblance to the subject it portrays. Therefore, the substance of the data can often be difficult to interpret by the untrained eye.
1.4 Depth Cueing

Most human vision is stereoscopic: the right eye sees a view of the world that is slightly offset from that seen by the left eye. The brain uses the two images to estimate distance between objects. Binocular vision is a key, depth cueing technique. Depth cues are the visual features in an image that promote the depth perception. Generally, the stronger the depth cues, the more convincing the illusion of depth will be for the viewer. A number of visual depth cues are considered when displaying the data.

In this case the shipwreck data is animated in 3D in order to explore issues related to depth cues. However, the resulting images are displayed on a flat 2D screen. Therefore the employment of depth cueing techniques is essential to create the illusion of a three dimensional object on the screen.

Description of common depth cueing methods:

- **Binocular vision (stereoscopy)**
  
  Human vision exploits the overlapping field of view gained from binocular vision to estimate the relative distances and depths of objects. In 3D visualisation using cathode ray tube or liquid crystal displays, the image is effectively seen in 2D. i.e. the image is on the screen plane and has x and y
dimensions but no z depth. Display devices are available to simulate stereoscopy using polarised filters or red/green rendered images to be used with glasses with red and green filtered lenses.

• **Perspective**

Objects nearer to the viewer appear to be of greater size than similar objects that are further away. This simple premise is one of the strongest depth cues. Perspective works particularly well as a depth cue when parallel lines are within the field of view emphasising the change in size over distance. The lines converge as they extend into the distance. With 3D visualisation it is possible to represent data orthographically, i.e. with no representation of perspective, therefore to include perspective depth cueing in a visualisation is a deliberate action.

• **Motion Parallax: Object/Camera Motion**

Motion can be a very strong depth cue. Extremes of movement are easier to interpret than those which are subtle. Combined with occlusion, movement of an object in the field of view can significantly enhance the viewer’s understanding of the perceived space. The relative speeds of objects moving past each other in the field of view can provide useful depth cues. For example, looking through the window from a moving vehicle, objects in the distance appear to pass by more slowly than those close to the viewer. Objects on the distant horizon may appear to be static.

• **Depth of Field (blurring) and intensity.**

Objects that are in front or behind the focus of attention can be blurred to enhance the illusion of depth. Colour intensity usually decreases as the
viewers distance from the subject increases. e.g. mountain ranges appear to have reduced colour intensity as they recede into the distance.

- **Occlusion**

  When one object passes in front of another, it occludes the field of view. The viewer perceives the visible object to be closer than the occluded object.

### 1.5 The Research Challenge

Taking into account current methods of presenting data from multi-beam sonar and identifying where depth perception can be enhanced, the challenge with this research is to develop new visualisation methods to improve how shipwrecks are represented.

This investigation challenges the current default aesthetic by offering alternative methods of displaying complex point cloud data from multibeam sonar surveys. Two new methods are described, the use of *occlusion objects* and *locoramps*, which when combined with digital cinematography techniques, improve the representation of shipwreck point cloud data.

The research is practice led, in the sense that the new methods were developed during the process of working on specific shipwreck survey projects, and involves the collaboration of an artist/designer, maritime archaeologists and multibeam sonar specialists whose roles are described in more detail in Chapter 2.

A number of case studies are used to identify some of the specific issues involved in displaying point cloud data. Experimenting with data from the wrecks of HMS Royal Oak (Chapter 7) and SS Richard Montgomery (Chapter 8) led to the development of novel visualization methods.
The results were evaluated by members of specifically targeted audience groups, as described in Chapter 11.
2. Background

2.1 The Management of Protected Shipwrecks

The Protection of Wrecks Act (1973) allows the government to protect a shipwreck from uncontrolled interference. Designated sites are identified as being likely to contain the remains of a vessel, or its contents, which are of historical, artistic or archaeological importance. Administration of the Act and its associated licences is the responsibility of English Heritage, Historic Scotland, Cadw, Welsh Historic Monuments in Wales and the Environment and Heritage Service in Northern Ireland. All of these agencies operate within the remit of the Department for Culture, Media and Sport. Wrecks located in inland sites are also managed by the Department for Transport, Maritime and Coastguard Agency (MCA).

The majority of these designated sites are historic shipwrecks. In some cases Licensees are appointed to maintain and monitor the condition of the shipwrecks. Licensees tend to be locally based, qualified maritime archaeologists with an interest in the shipwreck. In cases where the wrecks are considered hazardous due to dangerous cargo or designated as “War Graves”, they are restricted from any interference unless under the direct supervision of the MCA and MOD.

The criteria for designation of wreck sites:

“Wreck sites may be comprised of the remains of vessels, their accoutrements, armaments, cargo, and other associated objects or deposits. Restricted areas may include that area of the sea bed around the wreck site considered appropriate by the Secretary of State to ensure its protection. Wrecks or wreck sites may be considered to merit designation if they contribute or appear likely to contribute significantly to the understanding of the past on account of their historical, archaeological, or artistic importance.”

(English Heritage 2006)
The maintenance of these sites has traditionally been carried out by the deployment of diver surveys conducted at regular intervals. In recent years the use of sonar technology has been investigated in a number of the scheduled surveys, primarily at the instigation of the Archaeological Diving Unit (ADU) led by Martin Dean at St Andrews University.

The ADU pioneered novel methods of deploying multibeam sonar in an attempt to improve the quality of data gathered from wreck surveys. The ADU held the English Heritage contract to maintain these sites from 1986 to 2003. During this time the Independent Sonar Head Attitude and Positioning (ISHAP) deployment system was developed. It was further refined during the period of the Rapid Archaeological Site Survey and Evaluation (RASSE) project based at St Andrews University and funded by the Aggregates Levy Sustainability Fund, administered by English Heritage (Bates et al, 2007) ISHAP allows placement of the sonar head closer to the target than standard systems and resulted in a significant improvement in the density and fidelity of the sonar data.

2.2 Shipwreck Salvage

Shipwrecks are salvaged for many reasons. In many cases, the cargo may be significantly more valuable than the cost of salvage, although treasure salvage tends to destroy the wreck rather than safely remove it from the seabed. Wrecks are usually subject to salvage if they are a potential hazard to other shipping since they often sink within close range of international shipping lanes (e.g. the MV California sank after a collision in the Malacca Straits). Another key justification for salvage is the presence of hazardous materials in the wreck. Both case studies selected for this investigation, HMS Royal Oak and SS Richard Montgomery, contain marine oil and
munitions which are considered to pose a significant risk to the environmental as
they inevitably deteriorate.
The more time salvage companies spend on site, the higher the cost in manpower
and equipment. Therefore, for economic reasons, salvage companies need to locate
a wreck, establish its condition and plan the recovery in as short a time as possible. If
the cargo is potentially hazardous (e.g. marine oil), risk assessment, containment
and recovery need to be carried out safely and quickly to minimize environmental
contamination.

Traditionally, shipwreck salvage companies will use diver surveys when conditions
allow i.e. good visibility, shallow depth, and weak currents. When depth, weather or
visibility, restrict the use of divers, sonar technology is used extensively.

Multibeam sonar is regularly used to create image maps of the wreck and
surrounding seabed. The results can give a reasonable overview of the wreck site
but detail is often lacking. Figure 2.1 shows a multibeam sonar image of the New
Flame wreck lying off Gibraltar created by Spanish survey company Geomytsa. The
resolution and applied colour scheme are typical of current industry standards.
In this case, the pale green colour represents the shallowest topography (reef and deck), darker green becoming lime green represents the mid depth range (reef and hull) then a gradient of blue to violet is assigned to the deeper features (sandy seabed). The colour range is arbitrary and selected by the surveyor who produced the image. The stern section of the New Flame wreck can be seen in the centre of image. However, the resolution is low and no details on or around the wreck can be recognised. Low resolution data as seen in this example is due to the survey vessel traveling over the site too quickly, resulting in larger gaps between the sonar signal reflecting off the target and returning to the sonar device.
2.3 ADvanced Underwater Surveys (ADUS)

ADUS was founded in 2005 by Martin Dean and Mark Lawrence, both former members of the ADU at the University of St Andrews. Between 1986 and 2002 the ADU was contracted to Government departments, latterly the Department for Culture Media and Sport, to provide practical archaeological advice on wrecks in UK Waters designated under the Protection of Wrecks Act 1973. In the latter stages of this contract the ADU made increasing use of geophysical techniques to make assessments of submerged archaeological sites.

In 2001 the ADU collaborated with researchers from Heriot Watt University and Scientific Underwater Logistics and Diving (SULA diving) in a pioneering project, ScapaMap, (Oxley, I, 2002) to make use of multibeam sonar to image the wrecks of the scuttled WWI German High Seas Fleet in Scapa Flow, Orkney. This technique was identified by the ADU as having a particularly useful application in the study of wrecks in that the resulting data produced very clear, easy to interpret images of wrecks lying on the seabed as well as providing quantifiable data that can be used for comparative surveys. It also became clear that the images of wrecks produced using this method had wide ranging applications in both professional and recreational markets, since the survey data is both highly accurate and metrical. This led to further research into the methodology and potential applications of multibeam sonar for high-resolution surveys of wrecks (Dean et al, 2006)

In 2002 the ADU surveyed the wreck of the SS Richard Montgomery as a research exercise, the results of which attracted widespread attention in the hydrographic survey community due to the high quality of the data. The wreck had been the subject of regular surveys since 1995, although the majority of these were diver surveys undertaken in low visibility conditions rendering optical methods of recording the condition of the wreck unusable.

In its introduction, the 2003 MCA report states:
2. The report focuses on the diver surveys which have been undertaken rather than sonar surveys. However, an image captured via multi-beam sonar in 2002 is included to give an idea of the lay-out and orientation of the two parts of the wreck.

3. Operations on this site are hampered by poor underwater visibility and strong currents, making the survey of this wreck hazardous.


The sonar image mentioned was supplied by the ADU.

As a direct result of this work, the newly formed ADUS was approached in 2005 by the Maritime and Coastguard Agency (MCA) of the Department for Transport to re-survey this munitions wreck in the Thames Estuary. In December 2005, I was invited to join the ADUS team with a view to developing new methods to visualise the Richard Montgomery survey data in 3D. This opportunity provided an ideal set of case studies for the research reported in this doctoral investigation.

Individual roles within the ADUS research team are as follows:

**Chris Rowland**

My principal role is to develop aesthetic 3D visualisations of the digital survey data collected by ADUS with a remit to provide 2D and 3D images that communicate the condition of the underwater site to the target audience. This includes the development of new methods to edit, render and animate the data for the 3D visualisation. Each survey and visualisation project presents new challenges in visual representation in aesthetic and technical management.
Mark Lawrence

Lawrence’s main practical role is the management and delivery of the technical and logistical aspects of the sonar data acquisition upon which the 3D visualisations are based. This includes the integration, installation and operation of the sonar system and its acquisition software, and the orientation, positioning and communication systems necessary for the collection of high quality, high-resolution multibeam data. Lawrence’s role also extends to the collation and initial post processing (cleaning) of the sonar data before handing over to Rowland to produce the final visualisation.

Martin Dean

Dean’s main role is the management of individual survey strategies necessary for each site. This includes specification of the equipment, the design of the deployment system and survey plan to achieve optimum coverage of the complex shape of wreck sites. After final editing and cleaning of the data, Dean undertakes a forensic analysis of the evidence embedded within the survey data to develop hypotheses about the events leading to a ship’s sinking, its current condition and an assessment of its long-term outlook.

2.4 Surveying Underwater Sites: An Overview

Although this investigation is focused on improving the aesthetics of digital images, gathering good quality, accurate data is paramount to the 3D visualisation. It is therefore necessary to understand the process of surveying underwater sites using multibeam sonar. The following sections give an overview of some of the technologies and methods used to gather the data.

The process requires a combination of specialist technologies and expertise. Variations in equipment and deployment methods depend on the specific conditions
of each site. The following section describes the key steps and technology required to gather the sonar data from which the 3D visualisation is produced.

2.5 What is Multibeam Sonar?

Multibeam sonar (SOund NAvigation and Ranging) is a specialised system that uses sound to gather depth information from the seabed. A sonar system measures the time that an emitted acoustic signal takes to travel to the seafloor and back to the receiver. A narrow-beam sonar measures the average range to just a small area on the seabed. A multi-beam sonar comprises many narrow beams adjacent to one another forming a fan shape (known as a swath). Each of these beams measures neighbouring points on the seabed. Together they produce one strip of a 3D range map of the seabed. As the sonar system moves along, it emits acoustic signals periodically that measure a series of 3D strips of the seabed. Putting these strips together gives the 3D map of the seabed and any wreck or debris lying on it. Multibeam sonar equipment is usually attached to the surveying vessel and its resolution is dependent on the depth of the water. ADUS used the Reson 8125 multibeam sonar device for this investigation (Figure 2.2).

Figure 2.2 Left: Reson 8125 multibeam sonar device. Right: Attached to ISHAPS

The vessel travels over the target site recording depth data in single lines of xyz coordinates called point clouds. These passes are later stitched together to produce an overall dataset of the site.
The sonar device emits sound in the form of a fan shaped swath with the beams spreading outwards from the transmitter (Figure 2.3). As the water depth increases, the space between the acoustic beams becomes greater, therefore lowering the resolution of the data. Because of this feature current multibeam sonar devices attached to a surface vessel have a limited depth range (approx 40 -50 metres) beyond which the data is too thinly spread to provide sufficient detail for our purposes.

2.6 Side Scan Sonar

Side scan sonar systems are usually towed behind a vessel. Like multibeam sonar, side scan transmits an acoustic signal and measures the energy in the return signal as it bounces off objects on the seabed. Objects that protrude from the bottom give a strong return echo and appear as light parts of the image. Shadows from these objects appear as dark areas in the image (Figure 2.4). Although side scan sonar is a useful tool for detecting objects on the seafloor, it does not provide any depth information. The resulting images are two dimensional.


2.7 Deployment with ISHAPS

A key factor in the acquisition of good quality data is the distance between the sonar head and the target, i.e. the shorter the distance, the better the data. In an effort to decrease the range between the sonar head and the target, and also to allow better penetration of acoustic energy underneath any overhang created by a shipwreck’s angled or inverted attitude, the ADUS Independent Sonar Head Attitude and Positioning (ISHAP) system can be deployed.

This allows the sonar head to be positioned at depths of up to 12m below water level, rather than a more conventional 1.5m. The ISHAP system is a self contained unit that is designed for rapid deployment (Figure 2.5) by fixing the relationship between its component parts. The components above the water surface triangulate the submerged sonar head’s position with the base station.

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2 The National Oceanic and Atmospheric Administration (NOAA) is a US federal agency focused on the condition of the oceans and the atmosphere
2.8 Deployment with Remotely Operated Vehicle (ROV)

When the distance between the sonar device and the target object is beyond 40 to 50 metres, the acoustic swath becomes more spread out and less focused. This results in the data having lower resolution. To combat this problem, shipwrecks that are at greater depths require the sonar device to be deployed on a submersible vehicle in order to get closer to the target.

Remotely operated vehicles (ROV) can be used for this purpose. The ROV is completely submerged during the survey and is controlled by an umbilical cable.
attached to the survey vessel. Data from the sonar device is passed to the surface via the umbilical chord.

Tracking the ROV’s position in relation to the survey vessel and the target on the seafloor is the biggest problem to overcome. Since the vehicle is moving independently of the survey vessel and is completely submerged (unlike the ISHAPS deployment described earlier) its position cannot be accurately tracked using satellite triangulation, which does not penetrate below the surface of the sea. Other methods of accurately tracking ROV mounted multibeam sonar devices are used (De Souza, E.C, 2007). For example, Short Baseline Acoustic (SBA) positioning systems use beacons lowered from the survey vessel into the water above the ROV. The position of the ROV is then tracked through a process of triangulation between the beacons and a transponder on the target ROV. Long Baseline (LBL) systems can also be used when larger target areas are involved. LBL requires the placement of beacon arrays on the seabed around the target area. The wider distance between the beacons produces greater ROV tracking accuracy.

2.9 Platform: The Survey Vessel

The ISHAP deployment system developed and used by ADUS has been designed to be used on “vessels of opportunity” i.e. work boats that can be hired locally at relatively short notice. This allows the team a certain mobility that would not be possible with a dedicated survey vessel. Ideally, the platform is capable of slow, consistent travel over the target site in various sea states and weather conditions. The skill of the boat’s skipper is therefore paramount in the collection of good quality data. The quality of survey data is influenced by a significant number of factors during the gathering process (Dean, Lawrence 2006)
2.10 Base Station Setup

The base station consists of a Trimble 5700 RTK system located onshore close to the site of the survey. This system accurately locates itself using satellite positioning (up to 14 satellites). The base station is then used as a fixed point to which the survey vessel’s location equipment refers (Figure 2.7). NASA positioning data is downloaded to verify the base station’s position throughout the survey. The base station is usually set up a day prior to the survey commencing to allow its location to be accurately detected.

![Trimble RTK Base Station](image)

Figure 2.7 Trimble RTK Base Station located on the roof of the Harbormaster’s Office, Scapa Bay

2.11 Summary

The surveys carried out for case studies in this investigation required all of the previously mentioned technologies to gather accurate bathymetric data apart from Side Scan Sonar. Although the Reson multibeam sonar head also gathers side scan data, the data is not bathymetrically accurate and therefore not useful for this study.

The placement of a stable base station close to the survey target site is crucial when using the ISHAP system. This allows all the data passes gathered from a tilting, yawing, moving ship (on a rising or falling tide) to be correctly aligned to each other.

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3 Bathymetry is the accurate measurement and mapping of underwater features e.g. ocean floors.
at a later stage. The base station is linked to the survey vessel by radio or null modem (mobile phone link).

The 3D visualisation created from the survey data relies on accurate metrical results, which can only be provided if all the technology works together properly. Any system failure during the survey can result in inaccurate data being gathered and render the whole exercise invalid. It is for this reason that it is necessary to outline the importance of the technical setup and expertise required to gather good quality survey data.
3. Overview of Contemporary Shipwreck Visualisation Methods

The contextual review took the form of a literature review (see chapter 4) and a review of contemporary methods used to visualize shipwrecks. Various methods of recording and representing shipwrecks are described. Two dimensional photographic mosaics, hand drawn maps and artist’s impressions are widely used analogue methods of representing shipwreck sites (Bowens, A, 2008). The use of sonar devices, side scan and multibeam, have become more common in recent years.

3.1 Photographic Mosaics

Photo-mosaics are 2D plans produced from sequences of photographic images recorded at regular intervals as the camera tracks over the wreck site. The resulting images are stitched together digitally using a process that corrects the optical distortion which is a feature of underwater optics.

The example here (Figure 3.1) was created by Hanumant Singh at Woods Hole Oceanographic Institute (WHOI) from the Titanic survey 2004. Dr Robert D Ballard, who re-discovered the famous wreck in 1985, led the survey.

Figure 3.1 Photo Mosaic of Titanic, Singh, H, Woods Hole Oceanographic Institute, 2004

The process of creating photo mosaics requires the creative input of the individual tasked with stitching the images together. It is not an automated process since the software cannot recognise the separate elements of each photograph to create
continuity across the matrix of images. A key restriction to creating photo mosaics is the clarity of the water column in which the shipwreck is found. Visibility needs to be at least 20 metres with strong lighting conditions prevalent in order to achieve acceptable results. The Titanic project required the deployment of highly powered mobile lighting rigs for illumination at depths of around 3.8km (2.4 miles) (Ballard R, 1987).

Photo-mosaics are commonly used in underwater archaeology when the conditions are appropriate. Shallow sites such as the 1653 Swan wreck off Duart Point in the Sound of Mull (approx depth: 12 metres) have been systematically recorded using various methods including photo-mosaics. The Swan site has been the subject of extensive excavation and monitoring since 1991 by Dr Colin Martin, St Andrews University.

Dr Martin’s approach has been to utilise mainly traditional techniques such as site drawings to record the site. His use of photo-mosaics required the development of a rigid underwater rig (Figure 3.2) to ensure that the camera was placed at the same height above the seabed for each exposure. The resulting matrix of images was treated in Photoshop software to correct optical distortions around the perimeter of each image (Martin, C, 2007).
3.2 Hand Drawn Site Maps

Over the extended period of the excavation and study of the Swan, Martin has produced a series of hand drawn maps of the site. These meticulously detailed images use an elegant visual shorthand style that allows the viewer to differentiate between items on the seabed which the archaeologist recognises as wreck artifacts and those which are simply site rubble. The standard methods for producing hand drawn site maps are described in *Maritime Archaeology: A Technical Handbook* (Green, J, 2004). The series of drawings, each representing one metre square of the site (Figure 3.3), were compiled into a single site map, a process which took years to complete (Figure 3.4). Martin describes the archaeological processes involved with the Swan project in his book *Scotland’s Historic Shipwrecks* (Martin, C, 1998).

![Figure 3.4 Colin J Martin, Detail from Swan site map](image)

3.3 Artist Impressions

The literature review has highlighted the widespread use of artist’s impressions to represent shipwrecks on the seabed. Where photographic techniques are hindered by sub aqua optical distortion, the artist’s impression has traditionally been the best guess at what a shipwreck may actually look like on site.
The discovery of the wreck of the Titanic by Dr. Robert D Ballard led to a series of painted illustrations of the wreck from video footage collected during the exploration of the wreck. The paintings by Ken Marschall (Figure 3.5) offer views of the wreck that are physically (and optically) impossible to produce any other way. The photorealistic detail is extremely convincing and leads the viewer to believe what they see as being an accurate representation (Ballard, R, 1987). To date there have been no bathymetric surveys of the wreck site so the accuracy of Marschall’s illustrations is not certain. Marschall has also illustrated Ballard’s other famous wreck discoveries, Bismarck (Ballard, R, 1990) and Lusitania (Ballard, R, 2009).

![Figure 3.5 Titanic, Bow section illustration by Ken Marschall, The Discovery of the Titanic, R.D.Ballard 1987](Image)

Artist’s impressions of wrecks are particularly prevalent in the domain of recreational diving, although traditionally two dimensional illustrations, they are widely accepted as having validity as dive planning aids for wreck divers.

The illustrative work of Rico Oldfield represents the most realistic illustrations currently available (Middleton, N, 2006). The majority of Oldfield’s images represent accessible, wrecks lying in relatively clear water which are of interest to recreational divers but which are of limited historic value. This image of the *Carnatic* (Figure 3.6), a wreck in the Abu Nuhas region of the Northern Red Sea was produced from a series of photographic reference images taken by divers. The wreck lies on the
seabed at a depth of 27m. The clear water, minimal sediment and good sunlight penetration, provides excellent conditions for photographing the wreck (Figure 3.7).

Figure 3.6 Rico Oldfield. Illustration of the *Carnatic*, Shipwrecks of the Egyptian Red Sea, Middleton, N, 2006

Figure 3.7 Stern of the *Carnatic*, Red Sea. Rowland 2009
Max Ellis also provides useful 2D illustrations of popular UK shipwrecks for divers published in UK DIVER magazine (Ellis, M, 2007); Ellis has illustrated approximately 100 of the UK’s most popular, accessible shipwrecks, which can be found as a series of wreck tours at the DIVER magazine website (Divernet 2010). Each illustration is adorned with helpful annotations to describe features of the wreck. In Ellis’s images, realism is sacrificed in favour of an illustrative style that provides recreational divers with a simple map with which to explore the wreck site (Figure 3.8). Shipwrecks found in UK waters are usually more difficult to record photographically due to the sediment in the water, which may influence the illustrative style of Ellis’s images.

Figure 3.8 Max Ellis, illustration of the Acclivity for DIVER magazine March 2007

Although different stylistic devices are in use in these examples, the common factor is that they are two dimensional. They represent a 3D object in a fixed 2D plane. It is therefore impossible for the viewer to interrogate the images from any alternate angle.

3.4 Sonar Side Scan Features

Sonar side scan is a method of mapping the seabed used extensively by underwater exploration companies. It is carried out by towing a sonar device that emits fan shaped pulses of sound toward the seabed at angles that are perpendicular to the direction of motion. I.e. the pulse emits sideways from the device. As the sound hits an object on the seabed it causes a sonic shadow to be cast behind the object. When
the resulting image is plotted it gives the illusion of an object standing proud of the seabed as seen in Figure 3.9.

Figure 3.9 Sonar Sidescan image of Steam Yacht Anona. BP Exploration 2002

This method of mapping the seabed is useful for finding objects such as shipwrecks or for tracking sub sea pipelines. However, it produces two dimensional images with limited metrical data. Distortion often appears in the images as a result of the sonar device following a meandering path as it is towed. Sonar sidescan is often employed as a “first look” technology to detect the location of sub sea objects prior to the use of a multibeam sonar survey (Flemming, B, W, 1982).

Side scan sonar technology is relatively inexpensive (compared to multibeam sonar) and is likely to have a continued role in searching large areas of seabed for target sites. Once sites are located, multibeam technology can be deployed to gather bathymetric data. Figure 3.10 shows the path of the side scan sonar as a vertical line in the centre of the image. The sonar signal emanates sideways from this path and reflects back when an object is encountered. The sonar reflection appears as a highlight in the image. Where the object prevents the signal from hitting the seabed, it casts an acoustic shadow. The length of the shadow gives some indication of the height of the target object.
3.5 Multibeam Sonar

The development of multibeam sonar technology has rapidly improved during the last twenty five years, primarily through the work of Reson Inc, Santa Barbara and Kongsberg Simrad, Norway. The *SeaBat* range of multibeam echo sounders by Reson dominates the current market for hydrographic surveys.

The Royal Navy routinely surveys UK coastal waters using this technology. During 2007, the hydrographic survey ship *HMS Echo* surveyed the Firth of Clyde near Glasgow and gathered sonar images of the sunken aircraft carrier *HMS Dasher*. Figure 3.11 shows a photograph of the carrier on active service compared to the sonar image collected by *HMS Echo*. 

![Figure 3.10 Side Scan sonar image showing acoustic reflection and shadow](image)
Although the rough shape of *HMS Dasher* is recognisable in the sonar image, the lack of detail is self evident. Colour is used to indicate relative depth; dark blue denotes the deepest feature and the shallowest (nearest to surface) features are in red. Irrespective of the target object, the survey industry uses this range of rainbow colours as the main default method of representing hydrographic data in software such as Fledermaus⁴ and Terramodel⁵.

This method of representing the relative depth of data through a colour spectrum has also been adopted by the ScapaMap surveys carried out in association with Heriot Watt University in Edinburgh. The project surveyed the eight remaining wreck sites of the WWI German High Seas fleet scuttled at Scapa Flow in 1919. These first surveys in 2001 presented reasonably good quality data, which was gathered with Reson multibeam sonar equipment as in the image of the *SS Dresden* (Figure 3.12).

The use of colour is arbitrary. In this case red represents the deeper points ranging through green to blue at the shallower points. This is an inversion of the colour scheme used by the Royal Navy in their survey of *HMS Dasher*. This is typical of the assignment of arbitrary colour to point cloud data prevalent in the survey industry.

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⁴ Fledermaus is commercially available software developed by IVS 3D for the analysis of bathymetric data.
⁵ Terramodel is commercially available software produced by Trimble to work with data gathered with their surveying hardware.
In the Spring of 2006 the wrecks were surveyed again by SULA Diving on behalf of Historic Scotland. The same *rainbow* method of displaying the data was originally adopted. The image of the *SS Brummer* (Figure 3.13) was published on the BBC website on November 8\textsuperscript{th} 2006 (BBC, 2006). During the same period, the ADUS team carried out a survey of the same wrecks and the author applied a novel method of mapping colour to the data using localised colour ramps. This method was later developed into *locoramps* (see Chapter 8) to promote a better representation of details in the data. The Scapamap 2 image of the wreck of *SS Brummer* can be seen in Figure 3.13 and the ADUS image (produced by the author) in Figure 3.14.
This method of applying more appropriate colour to the wreck data was also applied to the other German WWI wrecks in the vicinity: SS Köln (Figure 3.15), SS König (Figure 3.16) and SS Markgraf (Figure 3.17). The wrecks lie in depths ranging from 30 to 44 metres, the optimum depth range for multibeam sonar surveying with the ISHAP deployment system.

Figure 3.15 SS Köln, ADUS 2006

Figure 3.15 shows the high level of detail that is visible on the SS Köln’s decks and superstructure.

Figure 3.16 SS König, ADUS 2006

Figure 3.16 shows the upturned hull of the battleship SS König. The damaged areas show where salvage activity has broken up the hull to access valuable pre-Hiroshima steel from inside the wreck. These images (Figures 3.14 to 3.17)
represent the results of the author’s early visual experiments and are a preview of the results of this research investigation, which are described in detail in chapters 7 and 8.

Figure 3.17 shows the salvage damage to the upturned bow section of the battleship SS Markgraf on the seabed at Scapa Flow.

3.6 Industry Standard Methods of Rendering Multibeam Sonar Data

The most common sonar data, editing and display software packages in use by the maritime survey industry are Fledermaus and Terramode. There are a number of other off the shelf products that can be used to edit and display point cloud data.
Most of the alternatives are aimed at editing data from laser scanning devices, e.g. Geomagic\textsuperscript{6}.

These software tools allow the user to display point cloud data in a variety of styles. The following examples show the same data displayed using the options available in Fledermaus. The dataset used is from the 2006 ADUS survey of the wreck of SS Köln at Scapa Flow, Orkney. The colour ramp used is the default rainbow colour scheme in Fledermaus. The data is rendered as a polygon mesh, wireframe, flat surface and points.

![Figure 3.18 Köln wreck data displayed as polygon surface](image)

The polygon display method (Figure 3.18) drapes a mesh over a sub sample of the dataset to give the appearance of a solid surface. The resolution of the mesh is determined by the bin size\textsuperscript{7} selected by the user when Fledermaus converts the point cloud to its proprietary Pure File Magic (PFM) format. In this example the bin size is set to one metre. The smaller the bin size the higher the resolution of the polygon mesh. This method tends to stretch overhanging data down to the seabed, obscuring any detail that lies within the outline of the wreck. The resulting image tends to resemble a “jelly mould”. When used to display bathymetric data from large areas of

\textsuperscript{6} Geomagic provide reverse engineering software. They are based in NC USA.

\textsuperscript{7} “Bin size” refers to the discrete intervals by which the point cloud data is sampled. In this example the size refers to distance in metres.
seabed (Brown, J, 2006), this method is very effective as seen in the image of the Florida shelf created at Emporia State University (Figure 3.19).

The wireframe display method (Figure 3.20) is similar to the polygon mesh in that the bin size controls the resolution of the displayed data. In this example, the wireframe appears to define the structure more accurately than the polygon method since the wireframe lines appear to follow the shape of features on the wreck. Detail is still obscured by any overhanging features.
Selecting the flat surface display option results in the data being rendered as a series of horizontal square planes (Figure 3.21). The number of squares displayed also reflects the bin size of the imported data. All three of these display methods either simplify the data set or interpolate between gaps in the original point cloud.

When the data is displayed in its original point cloud format (Figure 3.22) as xyz points, there is no interpolation of the data. Nothing is added or removed. Data beneath overhanging wreck features remains visible.
3.7 Key Differences to Land Based Survey Systems

Point cloud data is not limited to underwater sonar devices. Many land based archaeological sites have been recorded using a variety of laser scanning methods which also produce point clouds. For example, LIDAR (Light Detection and Ranging) is an optical remote sensing technology that uses laser light to measure distances to target objects. LIDAR is referred to as a "time of flight" system since it measures the time that a pulse takes to travel to the target and return to the device, i.e. closer objects return the signal more quickly than distant. LIDAR is widely used to digitally record larger sites often from the air using aircraft mounted systems (e.g. balloons, aeroplanes).

For smaller sites and artefacts, use triangulation based compact laser scanning systems (e.g. Reigl, Leica) which produce much higher resolution data, down to 25 microns (micrometres), which can easily be converted into very accurate polygon meshes. English Heritage published a useful guide to these technologies and their applications in 3D Laser Scanning for Heritage (English Heritage, 2007) in which seventeen case studies are described.

The key differences between underwater sonar systems and the land based systems are resolution, noise and colour. All of the land based systems are capable of gathering significantly higher resolution data: multibeam sonar is centimetric at best, whereas laser scanners can record objects at 25 microns (or 0.025 mm). In addition, the density, changing temperature and detritus found in the water column can produce noise in sonar data. These problems are significantly reduced on land where such conditions are not prevalent. Land based laser scanning is often supported by optical systems to gather colour information from the target at the time of survey.

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8 Regle and Leica are manufacturers of laser scanning products used widely in archaeological surveys. Further information available at www.reigl.com and hds.leica-geosystems.com
This colour information can then be added to the point cloud data or texture mapped onto polygon surfaces created from the data. Underwater multibeam sonar survey data gathers no colour information. Optical methods used to gather colour on land based sites are not applicable in underwater scenarios due to the loss of light and colour as depth increases. This is further compounded by low visibility in the water column.

A further advantage in surveying land based sites is the possibility of fixing the position of the scanning technology in relation to the target. Fixed tripod positions are unlikely to move during the surveying process. In maritime applications, the technology is constantly moving due to the pitch, roll and yaw of the vessel on which the surveying technology is mounted. This is in addition to the constant change in tidal heights while the survey is being conducted. It is clear that many of the problems associated with maritime surveys are not applicable to land based technologies, where the technology is significantly more advanced.
4. Literature Review

4.1 Search Strategy

In order to identify academic work relevant to this investigation, the search strategy involved two stages. A review of archaeological journals that have published work related to the visualisation of submerged sites was undertaken. This was followed by a wider review of computer graphics publications focused on 3D visualisation techniques and their applications to point cloud data created with sonar. The literature review began in 2003 and has been repeatedly updated throughout the duration of the investigation, most recently in July 2010. Throughout the literature search, the availability of relevant academic papers was scarce. Very little research has been published in this field.

4.2 Archaeology Journals

A definitive list of 34 academic archaeological journals was compiled. This was refined to those journals dedicated to maritime or nautical studies. Journals with the most citations are listed here:

- Journal of Maritime Archaeology.
  Published by Springer Boston since 2006. ISSN 1557-2285

- International Journal of Nautical Archaeology.
  Published by Wiley Blackwell for the Nautical Archaeological Society since 1972. ISSN 1057-2414

- Antiquity
  Published by Antiquity Publications Ltd since 1927. ISSN 0003 -598X
  http://antiquity.ac.uk/index.html
A search of all articles from these publications using the key words 3D, sonar, shipwreck and visualization, resulted in no results relevant to this investigation.

4.3 Computer Graphics Database Searches

The search was widened to include computer graphics journals using key words in online databases. Inclusion of the IEEE Xplore and ACM GraphBib and Siggraph digital libraries brought a wider range of results. Keywords were used independently and in combinations. The single keyword that consistently achieved the highest rate of results was visualisation (and the American spelling Vizualisation). When this was combined with subject focused words such as sonar and occlusion, the results referenced the same articles as previously listed. None of which were directly relevant to the investigation. Details of the keyword searches and results are located in Appendix A.

Using the single keyword sonar, five results were recorded of which two articles were relevant:

**Paper 1: Visualizing Underwater Environments Using Multifrequency Sonar**


Chapman et al, describe their Seabed Visualization System developed at Hull University. The paper shows sonar data of the wreck of the Richard Montgomery rendered as a draped polygon mesh with a multi-coloured ramp applied (Figure 4.1).
Further case studies are described: a harbour in Holland and an underwater pipeline in England. The harbour wall case study uses low resolution sonar data to map the wall followed by a process of the user placing polygon cubes to represent the harbour wall’s structure. The sonar data is used as a template for reconstructing the topology of the wall. Texture and light is then added to increase “the realism” of the model. A similar process is applied to the SS Richard Montgomery shipwreck data resulting in the replacement of the sonar data by a simple, textured polygon model.

Similarly, the pipeline visualisation follows the same process of replacing sonar data with simple 3D polygon reconstructions (Figure 4.2).
The paper describes the skepticism of a number of clients about the accuracy of the replacement models used in the system. To validate their approach, a comparison is made between ROV video footage of the pipeline and an animation of the 3D reconstruction. However, the authors inaccurately describe the pipeline model in their system as "sonar generated" when it is, in fact, constructed from polygon primitives using the sonar data as a guide.

In their conclusions, the authors state that the "Seabed Visualisation System offers a powerful and unique visualisation tool that brings together advanced technologies from sonar and computer graphics". p65.


The paper investigates the visibility of point clouds. It states that points can only occlude each other if they lie directly in front of each other. In laser scanning, the resulting point cloud is usually reconstructed as a surface with additional information such as surface normals and colour. Visibility of the surface is dependent on the
normal direction, which on continuous meshes, is simple to compute. The triangular mesh uses back face culling to prevent faces on the reverse side from becoming visible through the object. The key question addressed in the paper is how to establish point cloud visibility without resorting to mesh conversion.

The paper proposes a method for selecting which points are displayed from laser scan datasets using a *Hidden Point Removal* (HPR) operator. The paper states: “Our operator intends to find the points that would be visible, if the surface they are sampled from existed. The HPR operator creates convex hulls by spherically flipping the points across the circumference of a circle centred on the viewpoint. The convex hull is then utilized to define a boundary edge which can be then used to determine if a point is at the front (viewable) or back (hidden) of the scanned object in relation to the viewpoint.

Although this method works effectively with dense ordered datasets created from laser scanning, it is not directly applicable to multi-beam sonar data. This method is also limited to single viewpoints of the dataset and does not support movement of the object or the viewer’s position.

### 4.4 Cross Search

With such limited results from the archaeology and computer graphics subject domains, the search was expanded to a wider range of subject areas. Further online searches were carried out using *Cross Search* through the University of Dundee library services. As the name suggests, this facility allows searches through a number of cross disciplinary databases aligned to subject themes.

Using the Humanities, General and Computing, Mathematics and Physics subject themes, *Cross Search* accessed the databases listed in Appendix A. Using the
keywords Visualisation and Shipwreck, the search returned 7 results including the Chapman et al, 1999 paper mentioned previously. Two of the papers were considered to be relevant:

**Paper 3: New Developments in the Use of Spatial Technology in Archaeology.**

This paper gives an overview of current technologies in use for land based archaeology and does mention visualisation in broad terms, defining two approaches: *data visualisation* and *representative visualisation* which often use similar methods but have different goals. *Data visualisation* is aimed at discovering new patterns or relationships in abstract datasets whereas *representative visualisation* is the production of direct representation of archaeological evidence e.g. maps of sites or digital reconstructions. A further characteristic of representative visualisation is the ability to see the data from the viewer’s perspective.

The paper reviews the application of spatial technology in archaeology and how it can be classified into three categories: visualisation, data management and spatial analysis. However, the paper does not reference the use of multibeam sonar and simply points out that most land based geographic information system (GIS) techniques are not applicable to maritime environments. The wide range of referenced works in the paper proved useful in gaining an overview of land based archaeology techniques using light detection and ranging (LiDAR), global positioning systems (GPS) and geophysical methods, referring to these as “spatial technology”. A key point the paper makes is that investigations using these technologies are essentially non-destructive.
Here the authors describe a system to combine various archaeological data types using a central navigation device of a 3D shipwreck model (produced in VRML or Java 3D). The paper includes references to the inclusion of 3D representations of objects found at the site of the wreck. Various classes of data, e.g. text, photogrammetry, photography, are accessible via the interface.

Figure 4.3 Shows the 3D map of the wreck with locations of archaeological findings (Etruscan amphorae) placed on the map by the end user.

The paper describes stages of development of a tool to allow the visualisation of scenes by archaeologists without the need for expert knowledge of photogrammetry. The paper is based around findings from sixty metre deep wreck off Grand Ribaud Island in the Mediterranean Sea. The authors state:

“The wreck is resting at a depth of 60 meters; even if divers are able to go to that depth, the work is very difficult and potentially dangerous. A diver can not stay more
than about ten minutes at this depth and to establish a topographic map under those conditions would be near to impossible.” Chapter 2.2.1 p19.

The authors propose the three-dimensional model as an interface to the data, formalized in extensible markup language (XML), allowing the purely documentary data (references, observations made during the excavation, photographs) to be linked to a three-dimensional representation of the object. This graphic expression of the object relies on the data (position, orientation, and dimensions) and on the generic knowledge of the object (theoretical shape, default values, relationships between various objects). The three-dimensional model, generated by the system, shows the generic model of the object, defined by the archaeologist, measured by photogrammetry and thereby providing a relevant interface between the user and the collected data.

4.5 Grey Literature

The review of academic journals, even when extended to include the wider field of computer graphics, did not reveal any significant prior research specifically in the same field as this PhD investigation. Therefore the search was further extended to reports, newspaper articles and other grey literature sources. The relevant results were limited in number and related mainly to articles referencing the author’s own work. As the study progressed early results were presented at a number of conferences, resulting in publication in proceedings, magazine and newspaper articles. These are listed in chapter 13.
5. Research Questions

This research investigates how creative and aesthetically considered visualisation of 3D data from multibeam sonar can improve the viewer’s experience, understanding and appreciation of underwater shipwreck sites. The contextual review establishes that examples of academic research in this area are scarce (see chapter 3 and 4).

Aesthetic considerations in the presentation of scientific data are mainly contained to visual analytics, which deals with the process of presenting large abstract datasets in visual form to promote visual interpretation and pattern detection. Even here, colour choices are often arbitrary. As Eduard Tufte describes in *The Visual Display of Quantative Information* (Tufte 1983)

“Colour often generates graphical puzzles. Despite our experiences with the spectrum in science textbooks and rainbows, the mind’s eye does not readily give a visual ordering to colours, except possibly for red to reflect higher values than other colours.”

Theory of Data Graphics, p154

Tufte goes on to describe a method for colouring data as used by L. L. Vauthier (Funkhauser H. G. 1937), called the *mountain-to-the-sea* method. White is used to represent greater intensity since it was the colour of snow on a mountain, next came green, representing forests farther down the slopes, yellow for the grain in the fields then minimum values were coloured blue, the colour of the sea (Tufte 1983).

Although many areas of science present data using colour, often to define thresholds or significant places where change is evident (e.g. DNA profiling, heat maps) only the use of red to define hotspots or high values in a dataset appears regularly.
This arbitrary approach to colour use is typical of the rendering methods used in the display of maritime data in the heritage and salvage industries. Variations of rainbow colouring of data are common and are most often used to describe the depth of the data in relation to the surface of the sea.

This use of colour when displaying shipwreck data was one of the key issues considered when formulating the key research questions that underpin this investigation.

5.1 The Questions

The primary research questions:

• What are the most significant factors in displaying point cloud data of shipwrecks from multibeam sonar?

• Which current methods of visualising shipwrecks from multibeam sonar can be improved?

• Can the use of aesthetically considered colour improve the rendering and display of shipwreck data?

These questions are addressed through a number of case studies using 3D data supplied by colleagues in the ADUS (Advanced Underwater Surveys) research group.
5.2 Authorship

My role within the ADUS research collaboration has been clearly defined (see Chapter 2, 2.2). Throughout the process of collaboration, the question of authorship arises. The creative endeavor of each of the collaborative team contributes to the end result. In this investigation, my responsibility is in visualising the data gathered by the other team members. My authorship is grounded in the aesthetic representation of this data.

Estelle Barrett’s 2006 paper “Towards a Critical Discourse of Practice as Research” (Barrett, E 2006) discusses the subject of authorship. Barrett refers to the “Author function” described in Michel Foucault’s essay “What is an Author” (Foucault, M. 1991), where authorship is described as process rather than the production of an end product. Barrett reports:

“I believe his elaboration of author may help artist/researchers to: achieve a degree of critical distance in the discussion of their practice as research projects; locate their work in the field of theory and practice both within and beyond the specific field of creative endeavour and identify the possible gaps in knowledge that their research projects might address.”

Available at <http://sitem.herts.ac.uk/artdes_research/papers/wpades/vol4/ebfull.html>
[Accessed on 07/06/10]

Barrett suggests that “situated knowledge” (Haraway, D, 1991) operates on the basis of tacit knowledge as well as explicit knowledge to support a critical discourse of practice led enquiry.
This notion of situated knowledge is one that fits comfortably with my role as a creative practitioner in this PhD investigation. The 3D visualisations produced during the investigation rely on scientifically gathered, metrical data and not on an “artist’s impression” or reconstructionist approach. Therefore, my role is weighted much more towards representation rather than interpretation. The nature of my role as an artist/designer/practitioner, although relevant, is not a central theme to this investigation.

The influence of my role as artist/designer working in a collaborative, cross-disciplinary team could also be considered a valid research question. Tacit knowledge gained through the development of my practice and its application in research and industry is fundamental to the investigation. Other artists and designers tackling the same subject matter would most likely produce different outcomes influenced by their own tacit knowledge and experience. They may adopt similar methodologies and review similar literature whilst producing entirely different responses and outcomes. However, this issue is not central to the investigation presented here and is outwith the scope of this PhD study.

5.3 A Guide to the Chapters

This section describes the content of the remaining chapters.

Chapter 6 Strategy

The strategy for carrying out the investigation is outlined in this chapter. Diver surveys to gather primary reference images, industry standard methods for rendering multibeam sonar data and early visualisation experiments are described. The cyclical research methodology and use of case studies are introduced.
Chapter 7 Occlusion objects
This chapter describes how data from the HMS Royal Oak case study was used to identify characteristic problems when displaying point clouds in 3D. Initial experiments led to the development of occlusion objects, a novel method to improve the viewer’s visual perception of the shipwreck.

Chapter 8 Locally Oriented Colour Ramps
Data from the SS Richard Montgomery case study is used to explore methods to improve the use of colour to enhance details on the wreck. The development of locally oriented colour ramps is described.

Chapter 9 Digital Cinematography
The introduction of digital cinematography (e.g. virtual camera moves) to enhance the perception of depth cues in the wreck data is described in this chapter. Comparisons are made between still images and movie sequences with the example of “The Fallen Oak” movie used to highlight advantages in animating cameras around the dataset.

Chapter 10 Interactive Rendering: WreckSight
This chapter describes how occlusion objects, locoramps and digital cinematography were implemented in an interactive software application called “WreckSight” and examples of its adoption in the fields of diving, archaeology and salvage.

Chapter 11 Evaluation
This chapter describes the interactive survey tool used by recreational divers, animation students and maritime archaeology students to evaluate images rendered with the novel methods developed in this investigation. The results are analysed for statistical significance and are critically evaluated.
Chapter 12 Validation in Real World Applications

The adoption of occlusion objects, locoramps and digital cinematography by recreational diving groups, cultural heritage and the salvage industry is discussed. Expert users from these fields are interviewed and their comments evaluated. Other real world applications are described with reference to environmental hazards (B159 nuclear submarine) and examples of trade press coverage.

Chapter 13 Conclusion

This chapter summarises the research investigation and describes to what extent the research questions are addressed and how the results contribute to knowledge in the subject area. Impact of the work in the fields of diving, heritage and salvage is discussed and potential future work indicated.
6. Strategy

6.1 Methodology

In this investigation the research is both collaborative and interdisciplinary in nature. A multi-method research methodology is therefore appropriate (Brewer, Hunter 1989). Combining a number of research methods allows for a process of triangulation. The data produced can be examined from a number of different perspectives to cross reference the findings of the research (Gray, Malins, 2004). The multi-method approach promotes the use of multimedia to provide complementary sensory information. The use and interpretation of visual material (photographs, video, digital imagery etc) is a central process in this investigation.

The multi-method approach in this investigation reflects the characteristics defined by Lincoln and Guba in their definition of ‘naturalistic enquiry’ (Lincoln, Guba, 1985). Naturalistic enquiry is recognised by art and design researchers as a particularly appropriate research strategy where research happens in real world situations rather than in laboratory controlled conditions (Robson, 1993). The case studies represent the real world situation within which the visualisation design experiments take place. Another characteristic of naturalistic enquiry is the value placed on using the tacit knowledge of the researcher to develop emergent methodologies. The methodological approach is reliant on reflective practice and a cyclical paradigm.

Participatory action research follows a cyclical approach, applying the findings of one research cycle to the next iteration (Lewin, 1946). In its simplest form it follows a cycle pattern of Plan – Act – Observe – Reflect (Figure 6.1). Its origins are in social psychology, building on the work of Kurt Lewin (1890 -1947) but the principle applies in other disciplines where results developed in one case study are re-applied and built upon in further case studies.
One characteristic of participatory action research is its collaborative nature (McNiff 1995), which reinforces its relevance to my investigation. The research uses data sourced from case studies developed in collaboration with other members of the ADUS team. Each of the case studies presents a number of technical and aesthetic problems to be resolved. The findings from Study A will be applied and tested in the subsequent Study B. The process relies on the action taken to be evaluated, revised and applied iteratively.

This is also a good description of how the reflective practitioner operates in art and design (Schön D 1983). The designer identifies a problem, investigates it through the application of tacit knowledge and experimentation then searches for a suitable solution. Press and Cooper describe the principle categories of design research as formulation, evolution, transfer and reaction (Press, Cooper 2003), closely resembling the action research model while emphasising the creative process involved in reflective practice and research.

In summary, a multi-method approach is used in which case studies provide real world scenarios for experimentation. As new methods for improving the visualisation of shipwreck data emerge they are applied in a reflective, iterative cycle.
6.2 Strategy Overview

This investigation uses real world data gathered from the case study shipwrecks. The design and aesthetic of the 3D visualisation is informed by tacit knowledge gained through the author’s experience of art and design practice. The intention is to investigate new techniques to improve the way that shipwreck data is represented.

To achieve this, a strategy was developed that researches current knowledge in the field, identifies problems and areas for potential improvement, and then through experimentation develops solutions to these problems. The final stage is to evaluate the results with various target groups.

Key stages in the investigation:

- Survey contemporary shipwreck visualisation methods
- Review literature
- Visit shipwreck site in various states of visibility (diver surveys)
- Gather reference images (video and photography)
- Review how multibeam data is displayed in standard industry software to identify key visual characteristics
- Explore multibeam data from case study shipwrecks
- Experiment with visualisation methods to develop novel display methods
- Evaluate the results

The survey of contemporary shipwreck visualisation methods and literature review are described in chapters 3 and 4. The other key stages are described here in more detail.
6.3 Visiting Shipwreck Sites and Gathering Reference Images

Shipwreck sites were visited to carry out diver surveys. In the field of maritime archaeology, diver surveys are a standard method of investigating underwater sites to gather information about their current condition (Green, 2004). This experiential approach gives an insight to how the sites appear in reality on the seabed. UK sites can be unsuitable for diver surveys due to low visibility in the water because of particle matter or low light penetration in the vicinity of the shipwrecks (Edges, 1999). When conditions were suitable, underwater photography and video was recorded as a source of reference to inform the method of rendering the 2D and 3D visualisations.

There are significant limitations with using optical devices underwater. The underwater environment is hostile to electronics and this leads to the need for robust protective housings for cameras and lights. Light may penetrate to depths of over thirty metres in clear water (e.g. The Red Sea) however this is often hampered by plankton blooms, pollution and detritus in the water column. Underwater flash photography and video lighting can also produce a backscatter effect (Figure 6.2). Backscatter is caused by light reflecting back into the lens from floating particles in the water.

![Figure 6.2 Backscatter from underwater flash photography. C Rowland](image)
Overseas sites were identified where visibility and weather conditions were likely to be more favourable. e.g. the Red Sea. Table 1 lists shipwrecks visited and photographed during this doctoral study.

Table 1: Shipwreck Sites Visited

<table>
<thead>
<tr>
<th>Shipwreck</th>
<th>Location</th>
<th>Visibility (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMS König</td>
<td>Scapa Flow</td>
<td>&lt; 10m</td>
</tr>
<tr>
<td>SMS Kronprinz Wilhelm</td>
<td>Scapa Flow</td>
<td>&lt; 10m</td>
</tr>
<tr>
<td>SMS Markgraf</td>
<td>Scapa Flow</td>
<td>&lt; 10m</td>
</tr>
<tr>
<td>SMS Brummer</td>
<td>Scapa Flow</td>
<td>&lt; 10m</td>
</tr>
<tr>
<td>SMS Dresden</td>
<td>Scapa Flow</td>
<td>&lt; 10m</td>
</tr>
<tr>
<td>SMS Karlesruhe</td>
<td>Scapa Flow</td>
<td>&lt; 10m</td>
</tr>
<tr>
<td>SMS Cöln</td>
<td>Scapa Flow</td>
<td>&lt; 10m</td>
</tr>
<tr>
<td>F2</td>
<td>Gutter Sound</td>
<td>&lt; 10m</td>
</tr>
<tr>
<td>James Barrie</td>
<td>Hoxa Sound</td>
<td>&lt; 15m</td>
</tr>
<tr>
<td>Gobernardor Bories</td>
<td>Burra Sound</td>
<td>&lt; 12m</td>
</tr>
<tr>
<td>Doyle</td>
<td>Burra Sound</td>
<td>&lt; 12m</td>
</tr>
<tr>
<td>Tabarka</td>
<td>Burra Sound</td>
<td>&lt; 15m</td>
</tr>
<tr>
<td>SS Hispania</td>
<td>Sound of Mull</td>
<td>&lt; 10m</td>
</tr>
<tr>
<td>SS Rondo</td>
<td>Sound of Mull</td>
<td>&lt; 10m</td>
</tr>
<tr>
<td>SS Shuna</td>
<td>Sound of Mull</td>
<td>&lt; 8m</td>
</tr>
<tr>
<td>SS Thesis</td>
<td>Sound of Mull</td>
<td>&lt; 10m</td>
</tr>
<tr>
<td>SS Breda</td>
<td>Oban</td>
<td>&lt; 5m</td>
</tr>
<tr>
<td>RMS Aurania</td>
<td>Sound of Mull</td>
<td>&lt; 8m</td>
</tr>
<tr>
<td>SS Tapti</td>
<td>Coll</td>
<td>&lt; 15m</td>
</tr>
<tr>
<td>HMS Port Napier</td>
<td>Kyle of Lochalsh</td>
<td>&lt; 10m</td>
</tr>
<tr>
<td>San Tiburcio</td>
<td>Moray Firth</td>
<td>&lt; 5m</td>
</tr>
<tr>
<td>SS Somali</td>
<td>Farne islands</td>
<td>&lt; 10m</td>
</tr>
<tr>
<td>SS Christensen</td>
<td>Farne Islands</td>
<td>&lt; 12m</td>
</tr>
<tr>
<td>SS Thistlegorm</td>
<td>Gulf of Suez</td>
<td>Egypt &gt; 20m</td>
</tr>
<tr>
<td>Rosalie Moller</td>
<td>Gulf of Suez</td>
<td>Egypt &gt; 20m</td>
</tr>
<tr>
<td>Dunraven</td>
<td>Beacon Rock</td>
<td>Egypt &gt; 20m</td>
</tr>
<tr>
<td>Kingston</td>
<td>Shag Rock</td>
<td>Egypt &gt; 20m</td>
</tr>
<tr>
<td>Ulysses</td>
<td>Gobal Seghir</td>
<td>Egypt &gt; 15m</td>
</tr>
<tr>
<td>Miniya</td>
<td>Hurghada</td>
<td>Egypt &gt; 20m</td>
</tr>
<tr>
<td>Salem Express</td>
<td>Hyndman Reef</td>
<td>Egypt &gt; 20m</td>
</tr>
<tr>
<td>Carnatic</td>
<td>Abu Nuhas</td>
<td>Egypt &gt; 20m</td>
</tr>
<tr>
<td>Giannis D</td>
<td>Abu Nuhas</td>
<td>Egypt &gt; 20m</td>
</tr>
<tr>
<td>Chrisoula K</td>
<td>Abu Nuhas</td>
<td>Egypt &gt; 20m</td>
</tr>
<tr>
<td>Kimon M</td>
<td>Abu Nuhas</td>
<td>Egypt &gt; 20m</td>
</tr>
</tbody>
</table>

Diving these wrecks in different states of weather and visibility provided useful information on the limitations of optical (photography) and analogue (drawing) methods for accurately depicting shipwrecks on the seabed. Wrecks located in the UK were usually restricted to visibility of less than 10 metres. The exceptions being in areas of fast tidal flow (e.g. Tabarka and James Barrie) whereas the Egyptian Red Sea wrecks consistently had visibility levels of over 20 metres due to clear water and
good light penetration from bright sunny weather. When diving on a 100 metre long wreck in the Red Sea, the diver's view of the wreck is still restricted to a total of 40 metres (20 metres ahead and behind). In the UK this can be less than 10 metres in total. Hence the widespread use of sonar technology to produce an overall picture of underwater objects (e.g. shipwrecks, pipelines), supported by optical methods to examine details when visibility permits.

6.4 Reviewing Multibeam Data Display in Industry Standard Software to Identify Key Characteristics

The most widely used point cloud data visualisation software in maritime surveying industries is _Fledermaus_. It is the only software that is specifically designed for visualising data from undersea environments. Other packages such as _Terramodell_ can be used to view point cloud data from sonar devices but they are designed primarily for land based survey applications. _Fledermaus_ allows viewing and editing of point cloud data in a range of render styles (these are described in chapter 3). Data from the case studies was loaded into _Fledermaus_ and characteristics of the point cloud data were examined.

The key characteristics identified were:

- Points are rendered at the equal size, independent of their distance from the viewer
- Gaps between points allow distant points to show through
- Point cloud data from multibeam sonar contain no colour information.
6.5 Experimenting with Visualisation Methods

The experimentation process adopted for this study follows a reflective approach in which the findings of one experiment are used to inform the process of the next iteration. In design, this approach can be identified with participatory action research (O’Brien, 2001) in which collaborators interact to solve problems in a specific real-world context. The collaborators in this study include the members of the ADUS research team responding to the author’s visualisation experiments based on the case study data. Although each collaborator’s role is well defined within the team, an open debate was encouraged at each step of the visualisation development. Early results were shared with the collaborators and their responses noted. These experiments led to the development of *occlusion objects* and *locoramps* which are further described in chapters 7 and 8.

6.6 Evaluation of the Results

An interactive questionnaire was designed to evaluate the effectiveness of the novel methods developed through this study. The questionnaire asked participants to compare images rendered using *occlusion objects* and *locoramps* with standard industry methods and grade them in order of preference. In addition, expert users of shipwreck images and data from diving, salvage and heritage industries were interviewed to gain their informed opinion on the novel methods. This process is described in chapter 11.

6.7 Introducing the Case Studies

The case studies are based on data from real world projects supplied by ADUS. The selection of suitable case studies was based on a range of criteria. Each case study should be:
• Historically or environmentally significant (or both)
  o the visualisation is useful

• Suitable for multi-beam sonar survey
  o retain some recognisable structure

• Accessible during the research period
  o weather and depth permitting
  o within range of current sonar technology

The selected case study shipwrecks are of historical and environmental significance, requiring regular monitoring by UK Government agencies. The ADUS team was commissioned to produce high resolution sonar surveys of the wreck of *HMS Royal Oak* and the *SS Richard Montgomery* in 2006. These surveys provided an opportunity to access very high resolution data for this investigation.

*HMS Royal Oak* was sunk at anchor in Scapa Bay, Orkney, by U-Boat 47 in October 1939 (Snyder, 1976). The wreck contains a large quantity of munitions and marine grade oil which has been leaking into the bay since the sinking. The wreck is also a designated war grave and access to the site is restricted to MoD personnel and their authorised agents. The *HMS Royal Oak* case study provided the opportunity to explore and address depth cueing issues evident in point cloud data. This led to the development of *occlusion objects* as described in chapter 7.

The *SS Richard Montgomery* was a WWII liberty ship that sank in the Thames estuary in August 1944 after grounding on a sandbank (Hamer, 2004). The wreck is in two sections on the seabed in conditions of zero visibility. Remains of the masts are still visible above the surface. The wreck is 400 metres from the main shipping
lane and contains approximately 1,500 tonnes of live munitions. The SS Richard Montgomery case study data was used to improve the representation of details in the point cloud data leading to the development of Locally Oriented Colour Ramps (locoramps). This is described in detail in chapter 8.
7. Occlusion Objects

7.1 Surveying the Royal Oak

This chapter will describe how multibeam sonar data from the *HMS Royal Oak* survey was used to identify a number of problems associated with viewing dense point cloud data and how *Occlusion objects* were developed as a potential solution.

“The survey was so successful that it will now set the standard for all future wreck surveys and pave the way for advancing survey technology.”

Defence News: 30th October 2006 (Defence 2006)

7.2 Background

H.M.S Royal Oak (Figure 7.1) was one of five Royal Sovereign Class battleships constructed for the Royal Navy between 1913 and 1917, the other four being *Royal Sovereign, Resolution, Ramilies* and *Revenge*. Two units of the class, *Renown* and *Repulse* had been completed as battle cruisers.

HMS Royal Oak was constructed at Devonport Dockyard. Work started on the ship on January 15th 1914 and she was launched later that year on November 17th. The ship was commissioned in May 1916. HMS Royal Oak was completed with a
displacement of 25,750 tons and measured 580 feet in length with a beam of 88.5 feet and a draught of 27 feet. HMS Royal Oak served in WWI (1914-1918), fighting at the battle of Jutland, and was refitted between 1922 and 1924.

The Royal Sovereign class introduced a new feature to British battleship design, the anti-torpedo bulge. This was an externally attached compartment filled with air or water which was capable of exploding a torpedo prematurely on impact to minimise damage to the main hull. This type of deep bulge was fitted to the Royal Oak during the ship’s refit in 1924. Bulges also had the effect of reducing the roll effect at sea.

7.3 The Sinking of HMS Royal Oak

On the night of the 13th October 1939, U boat commander Gunther Prien managed to manoeuvre his submarine U47 into Scapa Flow through the narrow channel at Kirk Sound that had been thought to be effectively blocked by sunken ships to deter the enemy. Shortly after midnight U47 approached the unsuspecting Royal Oak lying at anchor in Scapa Bay (Kurowski 2008).

With the addition of torpedo bulges, the Royal Oak was thought to be well protected against submarine attack. After being struck by four torpedoes from U47 the ship listed to starboard and sank within 15 minutes, becoming the first battleship to be lost in the Second War. 833 men out of a crew of 1,234 aboard the Royal Oak died including its commander, Rear Admiral Henry Blagrove. As many as 401 men were saved from the sea, mainly due to the efforts of the vessel Daisy 2. Many of those who died are buried at the naval cemetery at Lyness on the island of Hoy. Gunther Prien returned to Germany to receive a hero’s welcome (Turner 2008).
7.4 Environmental Impact

When *Royal Oak* sank she had approximately 3,000 tons of marine grade oil onboard. Over the years, much of this oil has trickled out through corroding plates and slowly enlarging holes around rivets. This was not considered to be a significant problem until 1995 when traces of the oil were found washed up on Orkney beaches. The potential threat to local wildlife and fish farming businesses was considered to be a serious issue, resulting in Orkney Council approaching the Royal Navy with its concerns. Work to remove the oil began in February 2001. (Orcadian 2001)

Marine and Coastguard Agency NCA/ACOPS report 2001: states:

*Orkney and Shetland Islands January – December 2000 (9-OS/750).*

“The Orkney Harbours Department reported that a further 75 tonnes of fuel leaked from the wreck of HMS Royal Oak into Scapa Flow during 2000. The rate of leakage has increased in recent years and absorbent booms have been placed over the wreck to combat the pollution.”

(MCA 2001)

More recently, Ministry of Defence, Salvage and Marine Operations (SalMO) have been given the responsibility of removing the remaining oil through a process of *hot tapping*. The process involves fitting valves in strategic places on the hull. The valves allow oil to be extracted from within the wreck without risking any being released into the environment. Divers then attach a hose to the valve and the oil is pumped to the surface into a barge.

The wreck is now protected by UK government legislation and is listed as an official war grave, which prevents recreational divers from approaching the site. The Ministry of Defence, Salvage and Marine Operations (SalMo) unit are responsible for the
wreck and have been working on various methods to extract the remaining oil from the hull.

The first attempts involved attaching metal plates to the hull to cover the holes. Sandbags were then added as a secondary measure. There was some concern that any severe breach of the hull, through corrosion or impact damage, could cause a major release of oil all at once, with potentially devastating effect on the local environment.

The next plan was to construct a canopy that would catch and retain the oil as it floated to the surface. One problem was that the salvage team were not sure where the 72 onboard fuel tanks were located. These early attempts met with limited success (MCA 2001)

All the original ship’s drawings were destroyed during WW2; therefore the estimated configuration of the internal tanks is based on research and drawings of other ships in her class. The double bottom tanks immediately inside the hull contained about 50 per cent of the oil and the hot-tapping process has extracted the majority of this. There are inner tanks inside the wreck that could hold anything from 900 -1,600 tons of oil. In summer 2005, the SalMO team began to investigate these inner tanks. (Defence News 2006)
The inner tank boundary construction is thinner than the outer hull and it had been predicted that this boundary may have corroded over the years, allowing the oil contained within the inner tanks to migrate into the hot-tapped outer tanks. This could result in the majority of the remaining oil being removed through the hot-tap valves (Figure 7.2).

There remains a significant cargo of munitions in the wreck. Accurate information regarding the nature and condition of the munitions is not currently in the public domain. However, the ship was fully crewed at the time of the sinking and was most likely to be fully armed. Any significant movement of the wreck’s superstructure, through corrosion or other factors, would be likely to displace munitions with potentially catastrophic results.

SalMO commissioned the ADUS team to survey HMS Royal Oak in May 2006. The purpose of the survey was to ascertain the condition of the wreck and inform the planning of continued salvage of hazardous substances.
7.5 Schedule of Survey Operations

The survey took place from 7th to 12th May 2006.

The schedule of operations is shown in Table 2:

<table>
<thead>
<tr>
<th>Date</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunday 7/5/06</td>
<td>Equipment deployment</td>
</tr>
<tr>
<td>Monday 8/5/06</td>
<td>Patch testing</td>
</tr>
<tr>
<td>Tuesday 9/5/06</td>
<td>Survey Royal Oak site</td>
</tr>
<tr>
<td>Wednesday 10/5/06</td>
<td>Survey Royal Oak site</td>
</tr>
<tr>
<td>Thursday 11/5/06</td>
<td>Survey wider area: 400m</td>
</tr>
<tr>
<td>Friday 12/5/06</td>
<td>De rig equipment</td>
</tr>
</tbody>
</table>

Weather conditions on site were near perfect with no wind and excellent surface visibility. The sea state was calm throughout the operation allowing the collection of very high quality data. The survey vessel was the 15m general workboat *Flamborough Light*, an MCA category 2 work boat operated by D & L Launch Services, a small boat charter company based in Orkney.

For ease of operation the ADUS ISHAP system was attached to the port quarter of the survey vessel using straps and ropes (Figure 7.3), instead of being towed astern of the vessel. The single large propeller of *Flamborough Light* produced significant turbulence in the water, effectively preventing close quarter towing of the system directly astern. This in itself made no real difference to the survey since the ISHAP system is self-contained to prevent movement between the boat and the sonar head. Standard survey methods tend to place the various pieces of equipment in different places on the vessel depending on the space available. Since the ISHAP system is self contained with fixed distances between each element, it was possible to remove and re-attach the 8.5m long system without the need for time-consuming recalibration every time.
7.6 Locating the Base Station

A base station is required to be set up close to the survey site in order to accurately plot the relative position of the survey vessel as it traverses the wreck site. The position of the base station has to be accurately aligned using satellite tracking in order to compensate for the average 2.5cm tectonic plate movement that occurs every year. Although this 2.5cm movement is insignificant during the short period of the survey, it is necessary to factor in so that direct comparisons can be made with pre and subsequent survey data.

The shore base station was set up at the Orkney Harbour Offices at Scapa Bay, approximately 3km from the survey site. In order to ascertain an accurate position of the base station, it was set up ahead of the survey and programmed to gather raw observations of satellites. The longer the base station is in one location, the more accurately its position can be measured. Up to 14 satellites provided triangulated positioning information. GPS post processing software was then used to import Receiver Independent Exchange Format (RINEX)\(^9\) data from the Ordnance Survey active network for the collection period.

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\(^9\) RINEX: Receiver independent exchange format data is a data interchange format for raw satellite navigation system data.
7.7 Gathering the Data

Once the base station, ISHAPS and all associated equipment has been installed and tested, the survey begins. The movement of the survey vessel over the wreck site has been likened to "mowing the lawn". The vessel traverses the site in a series of parallel lines until the target area has been covered (Figure 7.4). In this case, the survey extended to 400 metres around the wreck.

A total of 29 passes were made parallel to the wreck to obtain data from the upturned hull and debris from the superstructure lying underneath. The sonar head was deployed at a fixed depth of 6.5 metres along the north and south sides then at 4.5 metres wherever there may have been a risk of collision. A further 17 passes were made to capture the surrounding seabed area. Each pass was approximately 400 metres in length and ran either due north or south.

Care was taken to ensure that no significant sections of wreck or seabed were missed during the data gathering process. Areas of the wreck that are beneath overhanging structure are particularly difficult to survey. This problem is partially mitigated by overlapping the survey passes so that outer edges of the swath penetrate beneath overhanging sections and pick up some details as shown in

Figure 7.4 Survey vessel on site. Note the green marker buoy on the left and oil slick emanating from the wreck
Figure 7.5. More data can be gathered from beneath overhangs by lowering the sonar device in the water column and rotating it to point towards the target area.

7.8 Processing the Data

After collection, the data was cleaned up by selective removal of unwanted noise. Noise tends to appear at the furthest extent of the range of the sonar head and often takes the form of points arranged in curved arcs. In the image example (Figure 7.6) the noise appears beneath the seabed. Other noise appears above the wreck, this could simply be fish in the water deflecting the sonar signal.

Editing out noise is a time consuming manual process that involves careful examination of each survey pass (line) over the site. Specialist survey software such as Terramodel or Fledermaus can be used for this part of the process. I used Fledermaus since it is specifically designed for use with maritime data. Any data that appears to be out of alignment, due to glitches in the global positioning system, is also rejected. The best lines are selected for use in the 3D visualisation. In this survey, out of 67 survey lines, 8 were used in the final dataset.
The selected lines are then combined to represent the complete shipwreck and its immediate surrounding area. Any details missing in any single line can often be found in other lines so an iterative process is necessary whereby data is re-examined until every possible detail of the wreck is extracted. Figure 7.7 shows individually coloured survey lines from separate passes over the wreck. Much of the overlapping seabed data is discarded with preference being given to survey lines that are straight with an even spread of data.
After further editing, the final dataset is created (Figure 7.8). The process described above removes all unwanted noise from the survey line data. The amalgamated lines produced a dense point cloud containing over 1.4 million points.

A linear grey scale ramp was applied to the data with dark grey at the deeper points, becoming lighter in the shallower parts of the wreck. Issues relating to point cloud colour are discussed further in the next section.

### 7.9 Characteristics of Point Cloud Data

As stated earlier, point clouds can be described as collections of Cartesian xyz coordinates in 3D space. When the data is gathered, the individual points contain only absolute positional information. Colour attributes can be added later to each point or to the point cloud as a whole. Colour is described as a combination of red, green and blue values (RGB).

When viewing point clouds, the shape of the object is represented by the positional relationship between individual points. For example, an array of points that are aligned along a common plane will be perceived by the viewer as a flat surface. This perception is reinforced by introducing depth cueing techniques such as perspective so that parts of the object which are closer to the viewer will appear larger than those
in the distance. Depth cueing reinforces the viewer’s depth perception when looking at 3D objects on a 2D display e.g. a computer screen.

Points do not have any inherent scale related attributes. When displayed, an arbitrary pixel size is allocated to each point. This size will differ depending on which software is used to display the point cloud. All points within the point cloud are assigned the same pixel size. This means that when the viewer is looking at a point cloud which represents a large object (such as HMS *Royal Oak*) a point that is close to the viewer will appear to be the same size as a point which is 200 metres away.

Gaps between points near to the viewer can allow distant points to show through. Since these distant points are displayed at the same size as the nearer points this can cause confusion for the viewer. It becomes difficult to perceive which points are contiguous and which are unrelated. Therefore the viewer finds it more difficult to clearly understand the shape of the object. This “gap between points” problem is common when viewing large point clouds in industry standard survey software such as *Fledermaus*.

The typical survey industry method for dealing with the “gaps between points” problem is to drape a polygon mesh over the point cloud. This process replaces the point cloud with a crude approximation of the shipwreck shape. The polygon mesh can be viewed as a *wireframe* (Figure 7.9), in which only the edges of each connected polygon are visible, thus allowing the viewer to see through the mesh.
The polygon mesh can also be viewed as an opaque surface (Figure 7.10). Therefore surfaces that are located close to the viewer will obscure surfaces that lie behind them. This may initially appear to be a solution to the gaps between points problem.

However, the use of draped polygon meshes introduces two significant problems. The draping process does not deal with overhanging structures very well. As seen in Figure 7.10, the polygon mesh simply draws a vertical surface that connects the
shipwreck to the seabed wherever it encounters an overhang. Any data gathered below the overhanging structure is therefore concealed.

![Figure 7.11 Royal Oak point cloud render](image)

In addition, as the draping process approximates the shape of the shipwreck, it fills in all gaps in the data. This has the effect of covering up any cracks or holes that actually exist on the shipwreck. Maritime archaeologists are often looking for cracks and holes as evidence of structural decay in the shipwreck. Polygon draping hides this evidence.

Comparing the polygon drape renders (Figures 7.9 and 7.10) to the original point cloud render (Figure 7.11); it is evident that more detail is visible in the point cloud even though the “gaps between points” problem is also clearly visible.

### 7.10 Initial Experiments in Maya

To explore methods of solving the “gap between points” problem the HMS Royal Oak data was imported into Maya an entertainment industry 3D animation and effects software package.
To import the HMS *Royal Oak* dataset into *Maya*

To import the HMS *Royal Oak* dataset into *Maya*, a conversion process is used to translate the point cloud co-ordinates into *particles*, a data format that is used to simulate natural phenomena such as fire or smoke. The conversion to particles allows exploitation of the extensive particle rendering tools in *Maya*. The software also incorporates a suite of dynamic simulation, polygon modelling and camera animation tools, all of which are useful for this investigation.

### 7.11 Draping

Initial experiments attempted to create more accurate polygon drapes by adapting cloth simulation tools. Cloth simulation uses surface collision detection to emulate how fabrics interact with modelled objects (Baraff, Witkin 1988). The simulated fabric is created from a high resolution, subdivided, flat polygon plane. This plane is placed above a modelled polygon object (e.g. a table) then allowed to fall and drape itself around the object. Where the fabric touches the table it will rest and its edges will drape around the object’s sides, like a tablecloth draped over a table.

The idea was to use this principle to create an accurate polygon drape which could then be wrapped around the *Royal Oak* dataset. The drape would be allowed to fall onto the wreck data from different angles in order to recognise data beneath the overhanging structure. Multiple drapes would be then combined to produce a composite polygon mesh.

This experiment produced inconsistent results with the method proving to be unreliable. The cloth simulator required a significant amount of processing time to calculate accurate results and system memory was insufficient to deal with the high resolution drape that was required. Had the cloth simulation idea worked efficiently, the resulting polygon mesh would still require further manual editing to reintroduce

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10 *Maya*: commercial 3D animation software available from Autodesk
real holes and cracks that were evident in the original point cloud dataset. This method could be further investigated in future when more powerful system resources might become available.

7.12 Occlusion Objects

Since the improved draping idea was unsuccessful, another approach was attempted. The plan was to retain the integrity of the point cloud data while developing a method to hide points in the distance that showed through the gaps between points close to the viewer. Thus solving the gaps between points problem.

The principle of occlusion objects is very simple. The basic premise is to create a visual barrier that masks out distant points that are visible in the gaps between points that are closer to the viewer. In 3d computer graphics, the simplest method of creating objects is to use polygons. Polygons are flat, rigid sided shapes usually with three (triangles) or four sides (quads). One of the simplest primitive shapes that can be modelled is the cube, each side of a cube is made from a four sided polygon placed at right angles to its neighbour. From these simple shapes, complex structures can be modelled. Using a polygon cube as an example, the principle of how an occlusion object works can be demonstrated.

Figure 7.12 Point cloud in the shape of a cube

Figure 7.13 Polygon cube placed in point cloud

Figure 7.12 shows a point cloud created in the shape of a cube. The points at the far side of the cube are clearly visible within the point cloud and confuse the viewer's
perception of the cube shape. When a polygon cube is placed inside the point cloud (Figure 7.13) those points are hidden from view (occluded) while the points in the foreground are still visible. Thus the cube shaped point cloud is easier to see.

Figure 7.14 Background colour set to black leaving only foreground points visible.

If the background colour is set to black (Figure 7.14), the occlusion object becomes invisible leaving only the foreground points visible. A short animation can be found in Appendix B 15.5 (DVD Rom) which explains this further with moving images.

This method was applied to the Royal Oak point cloud data. A simple polygon object was manually constructed to emulate the shape of the *Royal Oak* point cloud. The polygon shape was constructed to lie just within the outer shape of the wreck ensuring that it did not cover any of the exterior points in the dataset. Detail was added where necessary using standard polygon extrusion and subdivision tools. A sequence of images showing the build up of the *occlusion object* are can be seen in Figure 7.15. The resulting final polygon object was contained entirely within the 3D space of the point cloud.
The finished polygon object was assigned a matt black surface shader with no light defusing properties. When viewed against a black background, the polygon object became invisible. This polygon object was given the name *occlusion object*.

The basic principle was that whichever angle the viewer approached the wreck, the *occlusion object* would allow the points that occur between the viewer’s field of view and the polygon surface to be visible but would occlude any points that lay beyond. Since the *occlusion object* was constructed in 3D (i.e. not simply a 2D plane) the viewer would experience the same effect when traversing around the scene to establish different viewpoints.

The following sequence of 3 images, (Figures 7.16 to 7.18) show the effect of using the *occlusion object* in the Royal Oak shipwreck visualisation.
Figure 7.16 shows the point cloud only. The seabed on the far side can be clearly seen through the stern section of the wreck data.

The *occlusion object* is coloured with a blue shader in Figure 7.17 for illustrative purposes. The third image shows the *occlusion object* with a black shader as used in the final 3D visualisation.
Figure 7.18 shows how the placement of the occlusion object prevents the seabed from showing through the wreck data.

7.13 3D Visualisation Images Used in the MoD Report

The 3D visualisation identified various significant features on the wreck. The following images were rendered using the occlusion object technique that I developed and formed part of the final survey report delivered to the MoD in July 2006. In addition an interactive DVD was produced containing high definition animated sequences using occlusion objects, to show details of the wreck. Video footage recorded on site during the survey was also included on the DVD.

Figures 7.19 to 7.24 represent images printed in the final Royal Oak survey report for the MCA and Department for Transport.
Figure 7.19 shows the wreck as viewed from the South West. The rudder and prop shaft supports can be seen at the stern of the ship.

Figure 7.20 shows the starboard side of the wreck as seen from the North. Damage from four torpedo strikes can be seen at the bow and along the side of the hull near the seabed.
Figure 7.21 shows a view of the upturned hull. The prop shaft positions at the stern can be seen to the right of the image. On the left, a section of the bow has broken away and hangs down from the main wreckage.

Figure 7.22 shows a detail of the debris from the spotting top tripod spread along the seabed. A number of the ship’s guns can be seen at the top of the image. Individual points can be clearly identified in this close up. The points appear further apart at this
range but the occlusion object prevents seabed data showing through the point cloud of the main wreck.

Figure 7.23 Spotting top and related debris

Figure 7.23 shows a wider view of the spotting top. An upturned gun turret is visible at the top right of the image. Again, seabed data from the far side is blocked from showing through by the placement of the occlusion object.

Figure 7.24 Port side bow showing damaged hull plating
Figure 7.24 shows the bow section as seen from the port side. The bow plating torpedo damage can be send to the right of the image. Further damage was most likely caused by secondary explosions after the torpedo struck. Fuel for the onboard reconnaissance aircraft was stored in this area.

7.14 Summary

The Royal Oak proved to be an effective case study for this investigation. The conditions on site provided easy access to the protected wreck from Scapa Bay harbour. The base station was in line of sight of the survey ship, providing very accurate location data which made combining the separate survey passes into one image a simpler process than would normally be expected. The high quality data with clear separation of seabed from the main wreckage provided an ideal opportunity to experiment with methods to improve display of the data.

These experiments led to the development of the *occlusion object* as a method for improving the viewer’s understanding of the 3D space occupied by the wreck data. The use of the *occlusion object* prevented seabed and hull features from one side of the data from becoming visible from the other side. This proved to be a significant step forward in solving the “gap between points” problem. The *occlusion objects* method was applied to the other case studies in this investigation as a first step towards improving the visualisation of the point cloud data.

The use of digital cinematography in the visualisation also served to improve the viewer’s experience. This was particularly evident in the areas of the wreck near to the seabed where broken elements of the superstructure littered the seabed. The movement of virtual cameras across the scene helps to identify the separation of objects in the areas of debris. This is described in more detail in chapter 9.
In May 2006, the final 3D visualisation and report was presented at the MCA and MOD offices in Greenock to an audience representing the various interested parties. These included MOD personnel from SaLMO and the Northern Diving Unit who carry out the hot tapping, oil removal process, representatives from the Department of Transport and the Receiver of Wrecks. The overall response was extremely positive from all parties in attendance.
8. Locally Oriented Colour Ramps (Locoramps)

8.1 Surveying the SS Richard Montgomery

This chapter will describe the development of Locally Oriented Colour Ramps (locoramps). A method for improving the visualisation of detail in point cloud data, using multibeam sonar data gathered from the wreck of the SS Richard Montgomery in the Thames estuary.

Figure 8.1 SS Richard Montgomery. US National Archive

8.2 Background

The liberty ship SS Richard Montgomery was built in 1943 by the St. Johns River Shipbuilding Company in the USA. It was the seventh of the 82 such ships built by that yard. Liberty ships were cargo ships built in the USA during WWII. Over 2,700 were built on a modular design from sections that were welded together. The ships were used to supply European Allies with supplies of munitions when the USA joined the war effort. Each ship took an average of 42 days to build (Elphick, 2006).

Early liberty ships had problems with hull and deck cracks. During WWII almost 1,500 ships recorded instances of brittle fractures, a problem identified by Constance Tipper, a metallurgist at Cambridge University, as being caused by the tendency of
steel to change from ductile to brittle at critical low temperatures. Since many liberty ships passed through the North Atlantic, they encountered low temperatures which made them susceptible to fatigue cracks. Since the ships were welded rather than riveted, these cracks could develop unimpeded across the ship’s hull.

In August 1944, the SS Richard Montgomery left Philadelphia fully loaded with almost 7,000 tons of munitions (Figure 8.2) destined for the Thames estuary where it was to join a convoy heading to Cherbourg. On arrival at Southend, the harbour master ordered the ship to anchor off Sheerness middle sands (Figure 8.3).
8.3 The Sinking of SS Richard Montgomery

On 20th August, as the tide rose, the ship dragged its anchor and ran aground on a sandbank about 2.5km from Sheerness and 8km from Southend where it broke its back. It was reported at the time that other vessels in the vicinity had noticed that the ship was drifting and had sounded horns to alert the crew. The captain apparently slept though the whole event. Salvage of the cargo in the stern section began on 23rd August 1944 but further cracking of the hull caused flooding to the holds in the bow section. The salvage operations were abandoned on 25th September 1944, when it became completely flooded, with about half of the ordnance having been removed. After which the ship broke into two separate sections approximately at the mid point behind hold three. (MCA 2000)

Due to the presence of a large quantity of unexploded ordnance (approx 1.4 megatons) the wreck was designated as dangerous by the MCA under section 2 of the Protection of Wrecks Act 1973. There is an exclusion zone around the wreck marked by buoys (Figure 8.4) which are visible from Sheerness Harbour operated by
Medway Ports. In addition, the wreck is under 24 hour radar surveillance by Medway Ports.

Sections of the ship’s masts and lifeboat derricks are also visible above water. The wreck now lies upright on the seabed at a depth of approximately 22 metres and a short distance from the dredged channel to the Medway ports.

![Figure 8.4 Plan view of the wreck with position of marker buoys](image)

**8.4 Environmental Hazard**

The wreck’s close proximity to the Medway Ports channel puts it at risk from accidental collision. The channel is busy with traffic entering and leaving Sheerness harbour through the Thames and Medway estuaries. This is also the main access to the Grain Liquefied Natural Gas (LNG) terminal which was commissioned and made available for commercial operations on 15 July 2005 and was further expanded in December 2008\(^\text{11}\). The gas is shipped in and out of the terminal on huge tankers passing a few hundred metres from the wreck (Figure 8.5).

\(^{11}\) [http://www.nationalgrid.com/uk/grainlng](http://www.nationalgrid.com/uk/grainlng)
There is some debate surrounding the consequences of a shipping collision with the wreck. Inevitably, any impact would be likely to dislodge munitions within the bow section. However, there is some debate as to whether this would cause a chain reaction leading to an explosion.

Mick Hamer’s 2004 article for *New Scientist* (Hamer, 2004) discussed the possible scenarios based on published Government documents. He reports that most of the fragmentation bombs on board are fused. The fuses contain lead azide, a chemical designed to explode on impact and detonate the main TNT charge. Although the bombs are in watertight cases, the fuses are not. If water vapour were to react with the fuse, the lead azide would form hydrazoic acid, which in turn would corrode the detonating cap to form copper azide. This is highly sensitive and could explode with the slightest movement. One fuse detonating one fragmentation bomb could set off the rest of the cargo. The implications of a large explosion could be devastating for the surrounding area.

To monitor the condition of the wreck, the MCA has commissioned diver surveys since 1965, the most recent carried out in 2003. The first sonar survey was carried out in 2002 by St Andrews University to trial equipment for shipwreck studies. Further
sonar surveys have been undertaken by Sonar Research and Development UK Ltd in 2000 and more recently by ADUS in 2005 and 2006. The early surveys revealed that a crack in the hull by number 2 hold had grown from 12mm wide in 1965 to 17cm in 2003. Number 2 hold contains the majority of the fragmentation bombs listed on the ships manifest.

The ADUS surveys concluded that the most likely event to cause catastrophic damage to the wreck could be a violent storm. The superstructure leading from hold 2 to the surface is particularly weak due to cracks and general deterioration and would be most vulnerable to significant water movement during storm conditions. The remaining mast sections that protrude from the water (Figure 8.6) would be susceptible to bending and swaying, thus placing further stress on the wreck below.

Figure 8.6 Masts visible above the surface. Sheerness in the background

The MCA and Department for Transport commissioned ADUS to carry out a sonar survey of the wreck in 2006. The aim of the survey was to gather data of an appropriate type, and of higher quality and resolution than previous years in order to:
• Inform a detailed understanding of the wreck’s current condition and any patterns of change that may have occurred over time.

• Inform an understanding of the sediment regime around the wreck and any changes in that regime over time.

• Assess the potential for the wreck cargo to be dispersed through the ongoing deterioration of the wreck.

• Allow integration / comparison with existing datasets from the wreck.

8.5 Schedule of Survey Operations

The survey took place from 14th to 17th August 2006.

The schedule of operations can be seen in Table 3:

<table>
<thead>
<tr>
<th>Date</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday 14/8/06</td>
<td>Equipment deployment and patch testing</td>
</tr>
<tr>
<td>Tuesday 15/8/06</td>
<td>Survey SS Richard Montgomery site</td>
</tr>
<tr>
<td>Wednesday 16/8/06</td>
<td>Survey SS Richard Montgomery site</td>
</tr>
<tr>
<td>Thursday 17/8/06</td>
<td>De-rig equipment</td>
</tr>
</tbody>
</table>

Weather conditions were calm on site with very little surface swell. This proved fortunate when navigating between the two halves of the wreck. Any contact from the survey vessel could have dislodged munitions with potentially dangerous repercussions. The survey vessel was the 15m Wessex Explorer (Figure 8.7), an MCA category 2 workboat operated by a subsidiary of EGS Survey International Ltd. The skipper was very experienced in operating at slow speeds in survey conditions.
The variation in water depth over the wreck and surrounding area allowed the ISHAP system length to be exploited while maintaining a safe clearance between the sonar head and the wreck’s structure.

8.6 Locating the Base station

The base station was located above the Harbour Master’s office at Garrison Point, Sheerness, approximately 3km from the site (Figure 8.8). The wreck is in direct line of sight from the roof of the former defensive Battery. The Ordnance Survey coordinates of the base station were recorded as Easting 590850.257, Northing 175572.205 and elevation 19.377 (ODM). Using an RTK (real-time kinematic) positioning system, centimetric accuracy was achieved in X, Y and Z dimensions in real time. The short distance from the base station to the site of the Richard Montgomery helped to achieve this high level of accuracy.
8.7 Gathering the Data

In this case, rather than following patterns of regularly spaced lines, the helmsman monitored a digital display of the seabed (Figure 8.9) to ensure full coverage of the area survey. The display shows areas that have not yet been surveyed as greyscale. As the survey vessel passes over these areas, the seabed has a colour ramp applied. Since the display updated in real time, it was possible to spot any gaps and return to sections of wreck and fill them in. A total of 260 lines of data were gathered during the survey.

The area survey speed was between 2.4 and 5 knots. While over the wreck, the speed was reduced to between 1.2 and 3 knots depending on current and wind. When the survey vessel moves slowly over the target, the data collected will be denser. Denser data usually equates to a greater level of detail.
8.8 Processing the data

After the data was collected it was edited to remove noise using the same methods described in chapter 7. The resulting dataset is illustrated in Figure 8.10. The image shows the data rendered in *Fledermaus* with a standard survey industry rainbow colour ramp. The deepest points in the data are coloured blue and the shallowest points are red with a range of cyan, green and yellow in between.

8.9 Point Clouds and Colour Ramps

The use of this multi-coloured *rainbow* ramp to represent relative depth on survey data is widespread in the underwater survey industry. This method helps to reinforce the viewer’s depth perception when examining the point cloud since the wreck...
structure is usually located above the seabed and therefore would be assigned a different colour from the ramp. In Figure 8.11 the colour of the seabed sandbanks in the foreground, merge into the side of the ship’s hull.

The rainbow ramp method makes no attempt to represent the actual colour of the seabed or shipwreck features. The colour association is arbitrary. In the image (Figure 8.11) the deepest point is found below the stern at approximately 23 metres and is therefore assigned a dark blue hue from the colour ramp. However, when viewing a different point cloud, where the deepest point is at 50 metres, it would be assigned the same dark blue colour. The colour itself does not represent a specific depth but simply allocates a colour from the ramp relative to the deepest and shallowest points in the dataset.

In chapter 7, the Royal Oak data was rendered using a linear greyscale ramp where the deepest points at seabed level are assigned a dark grey and the shallowest points are assigned a much lighter grey colour. The image (Figure 8.11) shows the SS Richard Montgomery rendered with the same linear greyscale.

With shipwreck data such as the SS Richard Montgomery, where the wreck extends upwards from a relatively level seabed, a greyscale ramp can be effective in allowing the viewer to differentiate between seabed and wreck. The darker greys from the ramp will generally be assigned to data with lower Z co-ordinates in the dataset and
these lower Z values tend to represent the seabed. As the Z co-ordinates increase in value, usually representing the wreck as it rises from the seabed, the lighter greys are assigned. As can be seen in Figure 8.11, this creates a clear differentiation between the seabed and wreck. Further improvements can be effected by manually extracting points that represent seabed from the wreck data and applying separate greyscale ramps to the two resulting datasets.

This is not possible with all point cloud data, particularly where data is gathered from a wreck which is broken up or partially buried in sand or silt. In such cases it can be very difficult to identify which features represent seabed and which signify wreckage, therefore making separation of the points impractical. In these cases a single greyscale ramp is less useful to the viewer and the extraction of wreckage from seabed may not be possible due to the ambiguous nature of the data.

A similar problem occurs where there are many detailed features found within a small depth range e.g. 10 to 12 metres. A standard greyscale ramp assigned to the whole wreck does not allow for much variation so details become hard to see. For example, smaller objects on the deck may be difficult to differentiate from the deck itself.

The 2006 SS Richard Montgomery data is very high definition\textsuperscript{12} in terms of sonar contact points per square metre (approx 125/m$^2$ compared to 64/m$^2$ in 2005). Therefore it was possible to record a significant amount of detail across the deck surfaces, the holds and around the gun platforms. Details including safety railings, gunwales\textsuperscript{13}, debris from the masts and many others were captured during the multibeam sonar survey.

\textsuperscript{12} ADUS are capable of gathering upwards of 240 points per m$^2$ in 2009
\textsuperscript{13} Gunwales are the rails at the seaward edge of the deck.
The use of *occlusion objects*, as described in chapter 8, prevent the viewer from seeing through the gaps between points and therefore being confused by other points from the far side of the wreck that may be visible through the gaps. An *occlusion object* was created for the *SS Richard Montgomery*. Figure 8.12 shows the dataset without the *occlusion object*, the seabed from the starboard side is clearly visible through the wreck. In Figure 8.13 the *occlusion object* is applied, preventing this phenomenon. Both images are rendered with two greyscale ramps applied separately to seabed and wreck.

Although the use of an *occlusion object* in this case works effectively for the larger sections of the wreck, it would need to be refined much further to separate the fine detail on the decks. The *occlusion object* took approximately eight hours to construct. To refine it to the required level of detail would be exceptionally time consuming. A conservative estimate would be a further thirty hours to represent the main details on the deck using the *occlusion object* method. Therefore a more efficient method is required.
8.10 Locally Oriented Colour Ramps (Locoramps)

Locoramps were developed as a method to distinguish finer detailed features on the shipwreck data. This section will describe the stages of experimentation that led to this development.

Since we are working in a 3D environment where the X axis represents Eastings (East to West values), the Y axis represents Northings, for our purposes the Z axis represents depth. In Figure 8.14, the greyscale ramp assigned to the wreck data makes the features that are close to the seabed appear dark grey and those nearer the surface, pale grey. This occurs in a linear manner where black is assigned to the deepest points (lowest Z value) and white is applied to the shallowest (highest Z value). Therefore any point that is situated exactly half way between the maximum and minimum Z value will be assigned a fifty percent grey shade from the ramp.
Viewed from the south the wreck lies on an angle of approximately twenty degrees from horizontal (Figure 8.14). Traditionally in survey software, greyscale or colour ramps are applied along the vertical Z axis. When the wreck data is not perpendicular to the seabed, as is often the case, this can result in features found at the edges of the deck (e.g. the gunwales) being assigned different shades of grey. Similar features are not represented by consistent colours.

By carefully rotating the ramp to align with the prevailing angle of the wreck, similar features across the wreck can be assigned the same shade of grey. This produces a more coherent overall image with similar features on each side of the wreck being assigned similar shades from the ramp.

In addition, by inserting additional colour values at strategic points of the ramp it is possible to differentiate between details across the dataset. In the example (Figure 8.16) the ramp has been modified with red, white and green bands where it aligns

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14 Most survey software uses the Z axis as the height reference whereas 3D animation programmes usually refer to height using the Y axis ("Y Up").
with features on the main deck. The ramp is shown in the top right corner of the image. The bright colours are used here to simply to emphasise the effect of modifying the ramp at strategic points. Using bright contrasting colours makes the task of aligning the ramps much easier. After the ramp is correctly aligned it is a simple task to change the primary colours to more subtle alternatives. In the final version of the *Richard Montgomery* 3D visualisation only grey scale values were used in the ramps.

*Figure 8.15 Modified ramp rotated to align with deck features*

When the contrasting bands of colour in the colour ramp are placed closely together (red, white and green in this example seen at the top right of Figure 8.15) it is possible to pick out levels of fine detail that are not easily seen using a simple grey scale ramp. This idea was further developed using a small section of deck that appeared to be littered with debris. The ramp used in Figure 8.15 was modified further by adding thin stripes of varying shades of grey above the red line (as seen bottom right in Figure 8.16). In the example, Figure 8.16 shows how this process emphasises the definition of detail on the deck section.
The greyscale/colour ramp is applied to the whole dataset of the *Richard Montgomery*. The wreck is broken into stern and bow sections which are oriented differently to each other on the seabed. Therefore, a colour ramp rotated to align with the stern section may not be appropriate to assign colour values to the bow section.

Views of the whole wreck, from the west and above (Figure 8.17), illustrates this problem. The stern section shows the closely aligned ramp colours whereas the bow section is predominantly grey with only the top of the lifeboat frame picking up the colour green. The two wreck sections are located on seabed that slopes in different directions. Evidently, a single oriented colour ramp is not sufficient to assign appropriate colour to both sections of the wreck.
The immediate solution would be to separate the wreck data into two point clouds and apply a separate colour ramp with appropriate local rotation to each section. However, a greater level of control over how colour is applied to features of the wreck can be attained by taking this method a step further. Significant features can be identified, separated from the original point cloud and assigned an individual colour ramp. Each resulting ramp can be oriented locally to its wreck feature without affecting any other part of the point cloud. Also, by assigning multiple ramps with rotational independence, features that are perpendicular to each other can be appropriately managed.

For example, the cross section of hull visible where the ship broke in half can be assigned a colour ramp that is oriented at almost 90 degrees to the deck. Figures 8.18 and 8.19 show the cross section feature with a stepped colour ramp assigned. The green locator cross indicates the local orientation angle of the ramp. Each ramp is linked to a locator and when the locator is rotated the associated ramp also rotates. Once again, the bright ramp colours are useful to correctly rotate the ramp and are replaced with a modified grey scale for the final visualisation.

15 A stepped ramp has no interpolation between colour values and appears as a series of hard edged stripes.
The *Richard Montgomery* point cloud data was separated into 22 key features from the seabed, bow and stern sections as shown in table 4.
Table 4: SS Richard Montgomery data segments

<table>
<thead>
<tr>
<th>Seabed</th>
<th>Bow Section</th>
<th>Stern Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seabed turrets</td>
<td>Bow deck</td>
<td>Stern deck</td>
</tr>
<tr>
<td>Bomb debris</td>
<td>Starboard bulwarks</td>
<td>Midship deck</td>
</tr>
<tr>
<td>Seabed port side</td>
<td>Port bulwarks</td>
<td>Stern gun deck</td>
</tr>
<tr>
<td>Seabed starboard side</td>
<td>Bow gun deck</td>
<td>Starboard bulwarks</td>
</tr>
<tr>
<td></td>
<td>Bow end cross section</td>
<td>Port bulwarks</td>
</tr>
<tr>
<td></td>
<td>Bow hold silt</td>
<td>Stern hull port</td>
</tr>
<tr>
<td></td>
<td>Bow port hull</td>
<td>Stern hull starboard</td>
</tr>
<tr>
<td></td>
<td>Bow starboard hull</td>
<td>Prop and rudder</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stern end cross section</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stern silt</td>
</tr>
</tbody>
</table>

Each separate section was assigned an individual stepped colour ramp which was oriented to maximise the display of details on the wreck. The stepped primary colours in the ramps were replaced with edited greyscales. The seabed ramps were edited to resemble the sand/silt found at the wreck location in order to clearly define where the seabed ends and the wreck begins.

The locators associated with each section of wreck are shown in Figure 8.20. The locators are placed close to the point cloud data to which they are assigned.

Figure 8.20 SS Richard Montgomery with final edited locoramps and position of locators
The final 3D visualisation of the SS Richard Montgomery using occlusion objects and locoramps was presented to representatives of MCA, Department for Transport and MoD at the MCA headquarters in Southampton in October 2006. The following images (Figures 8.21 to 8.25) were included in the final survey report, an abridged version of which is available to the general public on the MCA website (MCA 2010).

Figure 8.21 SS Richard Montgomery View 1

Figure 8.21 shows clear definition between the seabed and shipwreck due to the application of separate colour ramps. The use of occlusion objects prevents seabed and hull data from the far side showing through the wreck data.
Figure 8.22 SS Richard Montgomery View 2

Figure 8.22 shows the wreck seen from the South East. The use of locoramps shows the finer details on the bow section. The gun platforms and edges of the holds are clearly visible.

Figure 8.23 SS Richard Montgomery View 3

Figure 8.23 shows the wreck seen from above. The higher points of the seabed sand dunes contrast with the grey scale ramps applied to the wreck data.
Figure 8.24 Views the wreck from the East. The separation between wreckage and seabed is clearly visible. Details on the deck are distinctly defined by the *locoramps*.

Figure 8.25 shows a profile view of the wreck as seen from the West. The height of the sand dunes is clearly visible along the hull of the wreck.

A series of animated 3D sequences were created that illustrated the condition of key features of the wreck. Structural deterioration such as cracks in the deck and hull were clearly identified in the visualisation. In previous reports these problem areas had only been described in text supported with an occasional diagram. The 3D animated visualisations were compiled on an interactive DVD to allow repeat viewing during briefings within MCA and Department for Transport. The DVD and report were used to brief Government ministers on the state of the wreck and to inform the development of the ongoing strategy to protect the wreck, its cargo and the local environment. Movies showing the wreck visualisation are available the DVDROM (Appendix B) and on the BluRay disk (Appendix C).
8.11 Summary

In this chapter the locoramp technique was developed. Building on previous work on the development of occlusion objects, locally oriented colour ramps (locoramps) enable subtle details in the point cloud data to be identified and highlighted in a way that makes them clearly visible to the viewer.

Experiments with segmenting the shipwreck data in areas of local detail (e.g. sections of deck) and applying separate colour ramps rotated to align with features of the wreck proved to be very successful. Subtle editing of the position, interpolation and contrast of colour and shade in the locoramps reveals small or subtle details in the shipwreck data.

Similar features on the wreck such as hand rails and gun decks are allocated similar colours by the application of locoramps. Industry standard methods of colouring would ordinarily apply arbitrary colour by depth resulting in these features being rendered in different colours.

Sensitive interpretation of the sonar data is promoted by the use of locoramps, assisting the viewer’s understanding of the shipwreck’s structure. Combined with the application of occlusion objects, the result is a representation of the shipwreck that can be viewed and understood by individuals without an in-depth knowledge of the visualisation techniques involved allowing critical information about the condition of the wreck to be extracted.

The 2006 SS Richard Montgomery survey provided extremely high quality data that contained finer detail than had been previously gathered using multibeam sonar devices. This can be directly attributed to the survey methodology using ISHAPS
developed by the ADUS team. Access to the data provided an ideal opportunity to experiment with ways of improving the display of this unprecedented level of detail.

The resulting still images and animated sequences from the 3D visualisation employing the use of *occlusion objects* and *locoramps* were well received by representatives of the MCA (the Receiver of Wrecks) and the Department for Transport.
9. Digital Cinematography

Cinematography is the aspect of film making in which composition (how the subject is framed) and camera movement are implemented (Mascelli 1998). Each type of movement is distinct from the others and follows accepted naming conventions in the film and television industries. For example:

- **Dolly**: camera is mounted on a wheeled platform and is pushed along rails while pointing at the subject. This is also known as a Tracking shot.

- **Zoom**: Camera is static but the focal length of the lens is altered over time.

- **Pan**: Camera is static but rotated around the Y axis.

- **Tilt**: Camera is static but rotated around the X axis.

Digital cinematography takes these principles and applies them in the digital domain. The depth cueing techniques described in chapter 3 are also applied to support the viewers experience when viewing the 3D visualisations.

9.1 Moving Image v Still Image

The one aspect of cinematography that differentiates it from stills photography is the element of movement. Using a virtual camera, the shipwreck data can be viewed from an unlimited range of distances and angles. The advantage gained by moving the camera is that motion parallax comes into effect. Motion parallax is the phenomenon of distant objects appearing to move more slowly than those close to the viewer as the viewer’s position changes (Rookes, Wilson, 2000).
This depth cueing effect can be exploited to emphasise the scale of the shipwreck in the visualisation by moving the camera slowly around the scene. Points lying close to the camera will pass the viewer much more quickly than those in the distance, thus enhancing the illusion of depth and scale. Viewing the data from multiple angles allows more comprehensive analysis of the shipwreck. Details that are not visible from one view may be revealed by moving the camera to a new position. As the camera moves, the viewer can gain a better understanding of the spatial relationship between the points and therefore a more accurate understanding of the structure of the shipwreck.

This spatial understanding can be explained by the gestalt theory of visual perception (gestalt is German for “pattern” or “organized whole”) (King 2007). Gestalt perception describes the cognitive process where the brain looks for meaning in visual patterns. In particular, our visual perception constructs a vision of the whole from rather than just a collection of lines and shapes that constitute separate parts. The six gestalt principles observe that our visual perception attempts to organise similar sized and shaped objects into groups when confronted with patterns.

The six principles of gestalt perception are described in table 5:

<table>
<thead>
<tr>
<th>Gestalt Principle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Proximity</td>
<td>Objects which are close together are perceived as a group</td>
</tr>
<tr>
<td>2. Similarity</td>
<td>Objects which are of a similar shape are perceived as a group</td>
</tr>
<tr>
<td>3. Common Fate</td>
<td>When movement occurs, objects follow a similar trajectory</td>
</tr>
<tr>
<td>4. Continuation</td>
<td>Preference for continuous lines is predicted</td>
</tr>
<tr>
<td>5. Closure</td>
<td>The tendency to close simple Figures to create a group</td>
</tr>
<tr>
<td>6. Area &amp; Symmetry</td>
<td>Smaller of two overlapping objects considered as Figure (foreground), the larger as ground (background)</td>
</tr>
</tbody>
</table>
The gestalt principles apply when we look at point clouds. Point cloud data can vary in density and consistency often resulting in complex structures on a shipwreck being represented by a few groups of points. By slowly changing the viewers angle of view (moving the virtual camera), the way in which these points align with each other can be explored, observed and better understood through the patterns and visual connections that emerge. Where the camera movement confirms that points are in line, describing parts of the same feature, the gestalt principle of *Continuation* is recognised. The *Closure* principle comes into action when the viewer perceives closed shapes that are merely suggested by the alignment of the points.

When the points observed to be close together in the point cloud are perceived to belong to the same wreck feature (gestalt principle of *Proximity*). All the points are identical in size in the point cloud but the deployment of locoramps purposely identifies similar colours with similar features, reinforcing the *Similarity* principle. Moving the virtual camera and introducing motion parallax reinforces the perception of points being connected when they appear to move together (*Common fate*). When *occlusion objects* are employed, points representing seabed and shipwreck features are more clearly defined and separated from each other since the seabed data does not show through the wreck data (Figure 9.1). This complies with the *Area* and *Symmetry* principles in that the larger seabed area is seen as ground (background) and the smaller wreck area is seen as Figure (foreground).
Non-moving or still images are useful for giving an overall impression of the wreck for publication in hard copy media but by nature they are restricted to single viewpoints. This restriction means that the composition of the images becomes more critical. The camera must be precisely placed to represent the data as clearly as possible. Multiple images are required to view the wreck from different points of view. The gestalt principles still apply to still images but they are restricted by the lack of movement that helps to confirm or reinforce the perception of depth in the image.

9.2 The Fallen Oak

The *Royal Oak* visualisation was first rendered as a series of short animated sequences which were individually selectable from a DVD menu. Each shot represented different features and views of the wreck and were designed to show details that revealed the condition of the wreck to support environmental management planning.

The principles of digital cinematography were applied to the *Royal Oak* data to communicate an overall sense of the wreck’s condition to a general audience beyond the original interested parties. A selection of the animated sequences were edited together to create a short movie entitled *The Fallen Oak*. The movie shows details of
the wreck including the torpedo damage and control tower debris in addition to wide shots of the whole wreck from different angles. The movie is intended as a 3D portrait of the wreck. Using occlusion objects and locoramps with digital cinematography, the wreck data is presented to paint as full a picture as possible of the wreck’s structure and condition. The short animation has a duration of 2 minutes, 40 seconds, and includes an original musical soundtrack composed by Farfletched.

The Fallen Oak movie has been screened at the Siggraph 2007 Computer Animation Festival in San Diego to an audience of over 20,000 in a period of five days. Excerpts from the movie were also broadcast on BBC 1 News to commemorate the sinking of the wreck. The Fallen Oak movie can be found in Appendix C. The images in Figure 9.2 show a selection of frames from the movie illustrating a camera move around the spotting tower debris area. The changing viewpoint allows the features to be seen from multiple angles, reinforcing the viewer’s understanding of the structure.

Figure 9.2 Image sequence from The Fallen Oak movie
9.3 Summary
Implementing digital cinematography into the 3D visualisations allows the viewer to analyse structures on the wreck that may have been difficult to identify from a still image. Gestalt theory helps to explain how moving the viewpoint, triggers pattern recognition in the viewer’s visual perception, thus improving understanding of the structure of features on the shipwreck.

The case studies described in the previous chapters (Royal Oak and Richard Montgomery) resulted in 3D visualisations presented as animated movies accessed through menus on an interactive DVD. This method of delivery is particularly appropriate when specific information needs to be communicated about a shipwreck, e.g. drawing attention to the individual locations of cracks in the hull on the Richard Montgomery or the damaged bow section of the Royal Oak.

Specific camera moves are designed to focus on the appropriate details. The animated camera shots are fixed once they have been rendered. The viewer is limited to replaying the movies either forwards or backwards but is unable to change the viewpoint. In the case of The Fallen Oak, watching the whole movie gives the viewer a more complete view of the wreck. However, the viewer still has limited control over how the data is viewed since this is decided by the animator when the virtual camera is animated and its viewpoint rendered.

To give end users the functionality to interactively explore the shipwreck visualisations, a real-time rendering approach was explored. This resulted in the development of the Wrecksight application which is described in chapter 10. As part of the evaluation process, a direct comparison was made between still images and movies of wreck details viewed from the same camera position. The results are described in chapter 11.
10. Interactive Rendering: WreckSight

10.1 Developing WreckSight

End users of shipwreck data such as salvage engineers and heritage agencies need to inspect shipwrecks and surrounding debris fields from many different angles to carry out risk assessment and salvage planning. This could be achieved by animating and pre-rendering movies to show every conceivable view of the wreck. However, the speed of camera moves would be fixed at the time of rendering and it would be impractical to produce hundreds of different animated shots required to view the wreck from every conceivable angle. A more efficient method would be to interactively move a virtual camera around the shipwreck data under the control of the user.

During the point editing process it is very useful to be able to rotate the data interactively in order to work out which points are caused by noise and which represent useful data. Rotating the data forwards and backwards by only a few degrees proves useful in this process, assisting the viewer’s visual perception in understanding the shape of the objects that the points represent.

The next step was to attempt to implement this level of interactivity into the final shipwreck visualisation along with occlusion objects and locoramps and the digital cinematography techniques described in the previous chapter. To investigate this further, a stand alone interactive application, Wrecksight, was developed in collaboration with a graphics programmer\(^\text{16}\).

The Wrecksight application combines the edited point cloud data from the shipwreck with the novel visualisation methods developed by the author in this doctoral study.

\(^{16}\) John Anderson, an independent graphics programmer wrote the code for Wrecksight
investigation: occlusion object, locoramps and digital cinematography. The
Wrecksight interface allows the viewer to rotate the wreck data and examine it from
any angle in real time. The point display size can be set to different sizes, the
smallest size (1 point) works best for wide views of the wreck and larger point size for
close ups. WreckSight retains the original global positioning data of the shipwreck so
each point has co-ordinates that relate to its depth below sea level (Z axis) and
position in Northing (Y Axis) and Eastings (X Axis).

The viewer can play back pre-designed camera moves across the wrecks, increasing
or decreasing the speed of movement in real-time. Alternatively, it is possible to
rotate, pan and zoom the camera around the 3D scene to explore the data
interactively. The display of the occlusion objects can also be switched off to allow
details inside the wreck become visible (e.g. cargo in the holds).

Tools that are useful for divers include the dive routes function which allows a diver
to place a shot line\textsuperscript{17} from the surface to any point on the wreck and then plot a route
around the wreck for their planned dive.

Distances and depths between turn points on the plotted route are displayed and the
total distance traveled is calculated so that a diver can estimate the time and air
required to travel the route. Once plotted, a dive route can be stored and viewed in
the 3D view superimposed over the wreck as shown in Figure 10.1.

\textsuperscript{17} A shot line is a rope attached to a floating buoy at the surface which is tied to a feature on the wreck.
The diver uses the shot line to guide themselves to a known position on the wreck.
The following section describes a selection of projects where shipwreck data has been implemented in the *WreckSight* application.

### 10.2 Wrecksight: Scapa Flow

At the end of WWI, the German High Seas Fleet was interned at Scapa Flow, Orkney. They arrived in November 1918, soon after the armistice, under the command of Rear Admiral Ludwig von Reuter. The seventy four ships became a local tourist attraction with boat trips taking visitors out to see them up close. On June 21\textsuperscript{st} 1919, von Reuter ordered the scuttling of the fleet. (Dan van der Vat, 2007)

Many of the ships were removed almost immediately with the majority being salvaged for scrap over the next few years (Bowman, 2002). The remains of seven of the ships are still on the seabed at Scapa Flow. Sitting at depths from 25 to 45 metres they lie within recreational diving range and have become a Mecca for wreck divers. The Scapa Flow wrecks are considered to be one of the most spectacular dive sites in the world, attracting over six thousand diving visitors per year.
Traditionally, divers have referred to artists impressions of the wrecks for orientation and dive planning (See chapter 3.3). Recreational dive magazines such as DIVER magazine regularly publish articles with shipwreck illustrations as “Wreck Tours”. The example in Figure 10.2 is an illustration of the wreck of SS Köln at Scapa Flow by Max Ellis which appeared in DIVER magazine in 2000 (DIVER, 2000).

Illustrations such as this are useful for pointing out the general layout of a shipwreck but the limitations of their accuracy becomes apparent when compared to the multibeam sonar image of the same wreck produced from ADUS data using the author’s occlusion object and locoramp techniques (Figure 10.3). In addition, a 2D illustration can only be viewed from one fixed angle, whereas the 3D data can be rotated and zoomed to be seen from any angle or distance.
ADUS gathered sonar data from the seven remaining German wrecks. The data was used to create *WreckSight: Scapa Flow* (Figure 10.4). The seven wrecks were incorporated into a single software application with which the user can select a wreck from the icons at the top of the screen then explore the exterior of the wreck by panning, zooming and rotating the data.

![Figure 10.4 SMS Brummer viewed in Wrecksight Dive Route tool showing plan and elevation views](image)

When diving on large shipwreck sites such as those at Scapa Flow, divers may descend down one shot line at the stern and ascend on another at the bow. Shot lines are regularly pulled from the wrecks by tidal forces and are not always replaced in the same position. In these circumstances divers returning to the wreck will find themselves at different locations when they descend the shot line. To replicate these scenarios, the shot line tool in *WreckSight* (Figure 10.4) allows the user to place multiple shot lines at different points of the wreck and edit the position of each shot for different dives. In addition, the surface of the sea is marked by a dotted blue line around the periphery of the shipwreck data. This gives users an idea of how far they may have to travel during a blue water ascent, i.e. ascending to the surface without using the shot line (Figure 10.5)
The prototype *WreckSight: Scapa Flow* software was distributed to the owner operators of Orkney's dive boat charters through the Orkney Dive Boat Owners Association (ODBOA) for evaluation during the 2007 diving season. Ten dive boat skippers tested the software with groups of recreational divers planning to dive the wrecks.

Feedback from ODBOA members was very positive. Divers used the software to gain a better understanding of the layout of the wrecks, plotting dive routes that linked features to act as landmarks throughout the dive. They also used the software post-dive to help describe where they explored and which wildlife and wreck features they had observed.

Previous sonar surveys of the Scapa Flow wrecks had been carried out as part of the ScapaMap project led by Historic Scotland and were made available as still images and scene files in the industry standard *Fledermaus* software. The limitations of still images and the problems associated with point cloud data (e.g. gaps between points) are inherent in the ScapaMap data.
Wrecksight: Scapa Flow uniquely displays the wrecks using the *occlusion object* and *locoramp* and digital cinematography techniques described in this thesis. The additional dive planning tools (e.g. plotting dive routes) further enhance the viewer’s experience of using the shipwreck data.

### 10.3 Wrecksight: HMS Campania

The *Campania* was originally built as a passenger liner for Cunard’s Liverpool to New York route in 1893. The ship held the Blue Riband from 1893-94 and was eventually sold to shipbreakers in 1914. The Royal Navy bought *Campania* and added a flight deck to the bow. The ship was the first to launch aircraft while underway. (Warren 1991).

The ship was anchored off Burntisland, Firth of Forth, in November 1918 when a storm caused it to drag anchor. After colliding with HMS *Royal Oak* and HMS *Glorious* it sank. In 2001 the *Campania* was designated under the Protection of Wrecks Act, 1973 as a site of historic importance. Therefore the wreck can only be dived under licence.

In February 2008, Historic Scotland approached ADUS and expressed an interest in using *Wrecksight* to display the remaining wreckage of HMS *Campania* on the seabed. The wreck lies in a low visibility environment (< 5m) and covers an area approximately 200m x 40m. The silty conditions and very low visibility make details of the wreck very difficult to record for archaeological purposes using traditional methods such as photography and sketching. Consequently, divers on the site have only a vague understanding of the orientation of the wreck and its features.
The multibeam sonar survey of the wreck was part-funded by Historic Scotland and coincided with ADUS sea trials of new Reson 7125 sonar equipment for the MOD. During the survey, high resolution data from the wreck of the *Campania* and a nearby sunken Grumman Avenger aircraft was gathered.

The *Wrecksight* implementation included data from both the wreck and the aircraft (Figure 10.6). The data shows the wreck sitting on a silty, flat seabed with many of the ship’s features partly buried in the silt. Although the main structure has been flattened by years of wave action and Navy clearance, a number of features can still be identified. The remains of the masts lie to the starboard side and a large section of hull can be identified along the port side. The Wrecksight screenshots (Figure 10.7 and 10.8) show the wreck rendered using a single grey *locoramp* with seabed data rendered using a brown shaded *locoramp*.

![Figure 10.6 Wreckage of a Grumman Avenger aircraft in the Firth of Forth.](image)

Figure 10.6 shows the Grumman Avenger on the seabed in the Firth of Forth. The wreckage lies on a flat area of seabed and is partially covered by silt.
Figure 10.7 shows the full length of the Campania wreck in the Wrecksight software. The wreck rises up to 8m from the seabed so the occlusion object has only a limited effect. The silt from the surrounding seabed has migrated across the low lying wreck, covering many of its smaller features. In this case, the subtle changes in the locoramp are used to separate details amongst the wreckage and silt, as can be seen in Figure 10.8.
Figure 10.8 Screenshot showing mast and details scattered across the wreck

The implementation of locoramps is particularly effective in this example. Standard methods of displaying the data (e.g. rainbow colour ramps) would not differentiate between the subtle changes in the silt layer and small features amongst the wreckage. WreckSight: Campania is currently being used to plan diver surveys of the wreck by the archaeological licence holder based at the Dive Bunker, Burntisland.

10.4 WreckSight: MV California

The cargo vessel California (Figure 10.9) was navigating the Malacca Strait between Malaysia and Indonesia, in March 2006, when the ship was involved in a collision with another vessel and sank in 32m of water in the busiest shipping routes between Europe and Asia. The Malaysian authorities recognised the wreck as a hazard to shipping, with its accommodation block rising to within 8m of the surface, and subsequently commissioned a salvage operation.
Dutch salvage company *Mammoet* were granted the contract to remove the wreck. Insurance for the loss of shipping at sea is provided by regional insurance “Clubs” which are funded by annual membership fees from the shipping companies. In September 2006, the American Club commissioned a multibeam sonar survey from *United Surveyors Pte Ltd*, to provide site information to the salvors. The report contained a number of multibeam sonar images gathered and rendered using standard industry techniques.

An image from the surveyors report can be seen in Figure 10.10.
After receiving the survey report, Mammoet contacted ADUS and commissioned a high definition multibeam survey of the wreck. Figure 10.11 shows the ADUS survey data displayed in *Wrecksight: MV California* incorporating the use of *occlusion objects* and *locoramps*. Note the significant difference in resolution and detail when compared to the United Surveyors image in Figure 10.10.
Mammoet made use of *WreckSight: MV California* in a number of ways. In the planning stage they used a portfolio of interim images to carry out a risk assessment and to negotiate the terms of the salvage operation with the insurers. From the detailed information visible in the shipwreck visualisation, it became apparent that Mammoet’s original plan to cut the vessel into sections was not viable since the hull plating was too badly damaged and would merely sway from side to side under the force of the cutting device.

During the salvage planning stage, Mammoet requested a new feature to be added to *WreckSight*’s functionality. They were keen to use the software during the salvage operation as a tool to guide divers to specific features on the wreck based on the global positioning retained in the data.

GPS information is inherent in the survey data when it is initially collected but in previous projects it was removed in order to normalize the edited point cloud and centre it at the origin (0,0,0). This was necessary to minimize the volume of 3D space that was required to import the shipwreck data in Maya for the construction of the occlusion objects and locoramps. Also, by normalizing the point cloud around the origin, it is possible to reduce each co-ordinate to 6 numerical characters or less. This can also reduce the file size by up to 50% which allows the application to be used on computers with less RAM and lower specification graphics cards.

*E.g.* An original x co-ordinate with a value of 185895.88 becomes 95.88 by subtracting 185800.00 from the original value. With this subtraction applied to all the co-ordinates in both x and y, the whole data set is moved closer to the origin (0.0.0)

The GPS feature was incorporated into the *dive route* tool in *WreckSight* by reverse engineering the point cloud normalising process. This resulted in the user being able to see the true Easting, Northing and depth co-ordinates for every point in the data by
rolling the curser over each point. The co-ordinates are displayed in the tool box at the bottom of the screen (Figure 10.12)

Figures 10.13 and 10.14 show screenshots from the WreckSight: MV California application.
Figure 10.14 California screenshot showing the dive route tool in plan and elevation views

Figure 10.14 shows the Dive Route tools. The user is presented with plan and elevation views of the wreck. The grid lines represent overall depth and distance, while the individual position of each point is displayed at the bottom of the screen as the cursor moves over the wreck.

This project showed that locoramps could also be used to highlight different materials in the shipwreck. The salvage company had a requirement to identify the amount of cargo (iron ore) that might still be in the wreck. The cargo had a salvage value and its removal required careful planning. To clearly identify the cargo visible in the survey data, a green locoramp was applied to visible features in the holds that still contained iron ore. In addition, the occlusion objects could be switched on and off to allow the cargo to be viewed through the side of the ship’s hull when required.
10.5 Wrecksight: MV New Flame

The *New Flame* left Gibraltar harbour without authorisation in the early hours of 12th August 2007 then collided with the Danish petrol tanker *Torm Gertrude* off Europa Point (Figure 10.15). The 190m cargo vessel was carrying scrap metal on route from New York to Turkey. In December the wreck broke in two and slid onto the “Los Picos” reef. Salvage company Titan were commissioned to remove the wreck by the Gibraltar and Spanish Governments.

![Figure 10.15 The stricken New Flame off Europa Point, Gibraltar. Photo courtesy of Titan Salvage](image)

Titan contracted a Spanish survey company, Geomytsa, to carry out a multibeam sonar survey of the *New Flame* wreck area in January 2009. Figure 10.16 shows an image of the wreck and surrounding are from the Geomytsa survey report. The wreck is represented by the blue shape in the centre of the image. The report was presented to a panel of government representatives from Spain and Gibraltar who have legal responsibility for this channel of water.
After reviewing the report, the panel’s observations highlighted that the lack of detail in the sonar images rendered the survey of limited use for planning the salvage of the wreck. The panel suggested that Titan contact ADUS with a view to conducting a higher resolution survey of the standard previously produce on the *California* wreck.

The ADUS survey took place in late January 2009 and the data imported into WreckSight. Titan salvage used *WreckSight: MV New Flame* to plan the salvage of the remaining stern section and engine room. The survey data confirmed that a significant amount of material had gathered in the aft hold which would require removal in advance of the salvage operation.

The following images (Figures 10.17 to 10.19) show the *MV New Flame* data presented in the WreckSight application.
Figure 10.17 shows the wreck lying across the Los Picos reef. The grey locoramps applied to the wreck data clearly differentiate it from the surrounding seabed. The lighter areas of the seabed locoramp represent the shallower areas of the reef. The depth of the reef increases towards the bottom right of the image and this is shown by the darkening of the seabed locoramp. The significant difference in depth in this area required the construction of a separate occlusion object for the seabed.
Figure 10.18 New Flame wreck on the Los Picos reef

Figure 10.18 shows the two main sections of the wreck lying across the shallower area of the reef. The deeper section and detail of the terrain can be seen in the top right of the image. Larger pieces of debris wreckage are also clearly visible.

Figure 10.19 New Flame wreck in WreckSight
Figure 10.19 shows details on the stern section of the wreck. The icons at the bottom of the image allow the user to playback the pre-designed animations across the data set.

Following the salvage operation, Titan Salvage was required to provide evidence that the wreckage had been cleared to a minimum depth of 17 metres. This is the minimum depth of the Los Picos reef upon which the wreck lies. ADUS returned to the site to carry out a post-salvage survey to provide this evidence. The post-survey data was added to the WreckSight: MV New Flame application to allow direct comparison with the data from the first, pre-salvage survey.

Figure 10.20 shows the pre-salvage visualisation which can be compared to Figure 10.21 which shows the post-salvage data with all features shallower than 17 metres removed.
The New Flame surveys provided an opportunity to directly compare two surveys of the same site conducted on different dates. The requirement to create an *occlusion object* for significant seabed features was introduced. Applying the same methodology of creating the *occlusion object* for the wreck data proved successful for the changes in seabed features. The use of *locoramps* on the seabed data emphasised details in the Los Picos reef and helped to clearly identify which wreck features needed to be removed to satisfy the 17m minimum depth requirements of the commissioning Gibraltan and Spanish Governments.

10.6 Summary

Each of the case studies described in this chapter provided challenges to visualise the shipwrecks as clearly as possible. Working with divers led to the development of additional features such as the plotting of dive routes and placement of shot lines to enhance the usability of the shipwreck visualisations.
The salvage industry (Titan and Mammoet) adopted the use of occlusion objects, locoramps and digital cinematography techniques as implemented in the Wrecksight application. The application was used for risk assessment, pre-salvage planning and post-salvage evidence of completion. In addition, the adaptation of occlusion objects to improve the visualisation of significant seabed features and the re-introduction of GPS data was instigated by an understanding of the salvage companies' requirements.

In the case of the Campania shipwreck, the majority of the wreckage lies close to the seabed with a maximum height of 8m. This meant that the occlusion object had limited effect whereas the subtle use of the grey scale values in the locoramp proved effective in revealing smaller wreckage details lying in the silt.
11. Evaluation

In this chapter the processes adopted to evaluate the effectiveness of occlusion objects, locoramps and digital cinematography techniques are described.

11.1 Triangulation

Three evaluation methods were used:

• Interactive online survey tool comparing the proposed new methods to standard industry methods

• Interviews with expert users in the fields of heritage, salvage and recreational diving.

• Appraisal of how the visualisation methods are adopted in real world applications

This triangulated approach allows results from different methods to be compared and combined to gain an overall view from a number of perspectives. Triangulation as a research evaluation method is useful in qualitative research, O’Donoghue and Punch (2003), define triangulation as a method of cross-checking results from multiple sources and methods to search for consistencies in research data. When the research follows a multi-method approach it is logical that the evaluation also should do so.

This chapter will describe the design and deployment of the interactive survey tool. The expert user interviews and real world applications will be discussed in chapter 12.
11.2 Ethics

Post Graduate research carried out at Duncan of Jordanstone College of Art and Design is required to follow guidelines on research ethics. A copy of these guidelines are available in PDF format in Appendix B, 15.6. Interview participants are given a participant information sheet which clearly describes the scope of the research project, the reason for their involvement and contact details for the researcher. After reading this, the participant is asked to sign a participant informed consent form, which includes permission to use the data in the research project. The questions to be used in the study are submitted to the ethics committee along with a clear description of the project. In addition to DJCAD guidelines, the University of Dundee operates an Ethics and Research Governance Policy, details of which are available online at: http://www.somis.dundee.ac.uk/court/policy/Ethics&_Res_Gov.pdf

This Doctoral research was conducted within the guidelines provided. All interviewees gave written permission to use their comments in the thesis. Participants in the interactive survey were presented with an information screen at the start of the survey which provided the information required to satisfy ethics guidelines. In particular, they were informed that pressing the "submit" button at the end of the survey represented permission to use their answers in the study. Examples of the forms approved by the ethics committee are included in Appendix A, 14.3.
11.3 Interactive Survey Tool

The interactive survey tool was designed to allow direct comparison between images of shipwrecks rendered with *occlusion objects* in section one of the survey, and both *occlusion objects* and *locoramps* in section two, to be directly compared with images rendered using standard industry methods. Data gathered with the survey tool will undergo statistical analysis to determine whether it is significant or not.

Each question in the survey takes the form of a page containing a set of four wreck images, each rendered using a different method (e.g. wireframe, *occlusion objects*, polygon drape etc) the participant is asked to grade the images from 1 (best) to 4 (worst) related to which image they regard as representing the wreck most clearly. Both section one and section two have four sets of images (questions), which view the same wreck from different angles and in a different order (e.g. the image using occlusion objects is not always in the top left or bottom right).

In section one, data from *HMS Royal Oak* is presented in four images each rendered from the same viewpoint. As described earlier, each image is rendered using a different method. Only one of the images employs the use of an *occlusion object*. The remaining images are rendered using standard industry methods (wireframe, polygon drape and point cloud). Figure 11.1, shows the layout of the four images in section one, question one.

After reading a description of the project and entering their name, participants grade the images by assigning a number from 1 to 4 where 1 is the highest preference and 4 the lowest. The third section allows the viewer to compare a still image with a moving image of shipwreck data using both *occlusion objects* and *locoramps*.

The render methods used in the images for section 1, question 1, are as follows:
To avoid any compositional bias, the image with the *occlusion object* is placed in a different position for each of the four questions and each question shows the wreck from a different viewpoint. This random ordering of the images is also applied in section two.

Section two displays data from the wreck of *SS Richard Montgomery*. In this section all the images are rendered using an *occlusion object* and point clouds. The colour is rendered using different standard industry methods in three of the images alongside one image where *locoramps* are used.

Figure 11.2, illustrates section two, question two. The colour render methods are:
In sections 1 and 2, the participant can also choose to view each image at a higher resolution to allow closer analysis.

Section three compares still images with movies of the same wreck data viewed from a similar point of view. Figure 11.3 shows the still image on the left and the movie on the right,
The four questions in section three show details from the *Royal Oak* and *SS Richard Montgomery* wreck data. The movies use slow camera rotations around the central point of the image. On-screen playback controls allow the viewer to review the movies repeatedly.

On completion of the three sections the participant is asked to add any comments in a text box and then click on a "submit" button. Their selections are then automatically emailed to a mailbox along with the time, date and their name as entered on the first page. The results are collated and subjected to statistical analysis. If the use of *occlusion objects*, *locoramps* and digital cinematography had a positive impact on 3D visualisation of the wreck data, the author would expect to see a high proportion the participating groups select the images using these methods as first choice. Results from the statistical analysis are described later in this chapter.
11.4 Participating groups

Three participating groups were identified for their awareness of and interest in shipwrecks, visual literacy in 3D imaging, and maritime archaeology techniques. These were recreational divers, animation students and post-graduate maritime archaeology students.

11.4.1 Recreational Divers

The survey tool was made accessible to a popular internet diving forum Yorkshire Divers (YD, 2010). The site has over 17,000 members and despite the name, they are from all over the UK with a small percentage from overseas. All of whom have an interest in recreational scuba diving and have an awareness of how shipwrecks are traditionally represented to the diving community.

The participants from the YD group were self selecting, accessing the survey between July 2009 and March 2010. A total of 107 people completed the survey during this period. Six of the submissions were discounted since they did not complete section three due to not having Quicktime player installed on their computers (they couldn’t play the movies). A further three submissions were identical to the default settings on the survey and were therefore discounted. A final total of 98 submissions were accepted for statistical analysis.

11.4.2 Final Year Animation Students

Final year undergraduate animation students (Class of 2009) at Duncan of Jordanstone College of Art and Design, University of Dundee, were selected as a participating group due to their visually literacy and good awareness of 3D technology and cinematography methodologies. To avoid any discussion between them, the eighteen participants completed the survey in a one hour media lab session on 27th May 2009.
11.4.3 Post-graduate, Maritime Archaeology Students

MSc students studying Maritime Archaeology at Bournemouth University completed the survey during May 2009. The course is based in the Centre for Archaeology, Anthropology and Heritage and is currently engaged in research on the designated historic wrecks in England. The students are aware of a wide range of techniques in maritime archaeology from traditional analogue to recent digital developments.

11.5 Analysis of the results: Statistical Significance

Results from each of the participating groups were collated and analysed to establish whether they were statistically significant. For each question in the interactive survey, a set of model answers were produced. The model answers grade the image rendered with the author’s new methods in each section as 1 and the industry standard methods as 2, 3 or 4.

For example, in section one, question 2 (Figure 11.4) the model answers were set as shown in table 6:

<table>
<thead>
<tr>
<th>Image</th>
<th>Description</th>
<th>Model Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image 1</td>
<td>Point Cloud &amp; Occlusion object</td>
<td>1</td>
</tr>
<tr>
<td>Image 2</td>
<td>Polygon Surface Drape</td>
<td>4</td>
</tr>
<tr>
<td>Image 3</td>
<td>Point Cloud</td>
<td>2</td>
</tr>
<tr>
<td>Image 4</td>
<td>Polygon Mesh Wireframe</td>
<td>3</td>
</tr>
</tbody>
</table>
11.5.1 Percentage of 1st Choice Agreement

The percentage of survey answers where the first choice in each question matched the images that contained the authors proposed new visualisation methods: *occlusion objects, locoramps* or cinematography, was calculated for each participating group.

This calculation shows how many participants prefer the new rendering method compared to three standard industry methods represented in the question. Whereas the correlation coefficient mentioned earlier compares the full set of grades (and their order) to the model answers in the participants’ responses, i.e. not just the first choice image but also the descending order of preference.

For example, where a participant selects the image with an *occlusion object* as first choice, the correlation coefficient will only give a value of 1 if the second, third and fourth choice answers also match the corresponding model answer. Identifying the
percentage of only the first choice preferences in each participating group removes
the subsequent second, third and fourth choices from the equation.

The results for each group are presented in Figures 11.5, 11.6 and 11.7 as follows:

![Figure 11.5 Recreational Divers % 1st Choice Agreement](image)

The recreational diver group was the largest number (98 results assessed)
contributing to the survey. The participants were from a wide range of backgrounds
with their interest in recreational diving being the common factor connecting them to
the survey. Therefore it is not surprising that their results delivered the most variation
from the model answers. However the percentage matching the first choice answer
was very high, ranging from 79% to 98% overall. A small number of outlying results
were evident. One respondent produced answers that were an exact inverse of the
model answers which suggests a misreading of the instructions (or simple mischief).
The *occlusion object* section delivered the closest match to the first choice answers
with an average of 91.5%. The *locoramps* section produced the lowest average of
80.5%.
The smaller group of animation students (18 results assessed) produced more consistent results than the divers. Again, the *occlusion objects* (Figure 11.6) section produced the highest average result with 95.5% matching the first choice answers. Note that with the smaller number of participants, a result of 94% is produced if only one person in the group does not match the first choice model answer. In each case where this occurred in the *occlusion objects* section, their first choice matched the second choice model answer. The cinematography section returned a high average result of 91.5% which is probably due to their understanding and interest in filmmaking in their area of study.

The *locoramps* section produced the lowest average result (80.5%).
The maritime archaeology group (15 results assessed) produced the highest percentage match to the first choice model answers in all sections: occlusion 96.5%, locoramps 92% and cinematography 93% (Figure 11.7). This equates to 1 or 2 students in each section matching their first choice with the second choice model answer. The participants in this group would be the most familiar with the images of shipwrecks used in the survey.

Overall, in Section 1 (occlusion objects) the results from each group are very similar with a high percentage average (92%, 95% and 96.5%) selecting the image with occlusion objects as first choice. In most cases, those that didn’t match the first choice model answers selected the second choice model answer instead.

Section 2 (locoramps) results have a slightly lower average percentage with 81%, 80.5% and 92% respectively choosing the image with locoramps as first choice. In Section 3, the average percentage selecting the moving image (digital cinematography) as first choice is 86%, 91.4% and 93% respectively.
11.5.2 Correlation Coefficient

The participant groups’ survey results were compared to the model answers for each question to test the level of agreement. The statistical method to measure this is to identify the correlation coefficient (Crombie 1996).

In simple terms, a correlation coefficient (or agreement value) of 1 identifies a positive relationship between the participants answers and the model answers. If there is no relationship (no agreement) then the value would be calculated as 0. A negative correlation would produce a value of -1.

The results would be considered statistically significant if the correlation coefficient is 0.6 or greater, when this occurs the link is described as strong. If it is less than 0.5 it is described as weak. The correlation coefficient from the survey results are collated in tables 7, 8 and 9. The relationship measured, is how closely the survey results match the predicted model answers.

Table 7: Correlation Coefficient: Recreational Divers

<table>
<thead>
<tr>
<th>Correlation coefficient</th>
<th>Recreational Divers</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section1: Occlusion Objects</td>
<td>0.87</td>
<td>0.90</td>
<td>0.90</td>
<td>0.85</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>Section 2: Locoramps</td>
<td>0.71</td>
<td>0.66</td>
<td>0.63</td>
<td>0.65</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>Section 3: Digital Cinematography</td>
<td>0.76</td>
<td>0.71</td>
<td>0.73</td>
<td>0.78</td>
<td>0.74</td>
<td></td>
</tr>
</tbody>
</table>

The recreational divers constitute the largest group in the evaluation (98) and therefore reflect a wider range of experience and knowledge of shipwreck visualisation. The results from this group show a very strong (0.88 average) correlation coefficient in the occlusion objects section but a lower level (0.66 average) in the locoramps section. This lower result may be due to the divers’
interest being in getting an accurate overview of the wreck during dive planning, which is primarily achieved by applying occlusion objects to the data. Observing fine detail might not be a priority for this group. Divers need to identify key features on the wreck in the restricted visibility of a dive. This could explain the lower score in the locoramps section where smaller details are emphasised. However, this is also the largest group of participants; therefore a wider variation in answers should be expected. The result of 0.66 is still statistically significant.

Table 8: Correlation Coefficient: Animation Students

<table>
<thead>
<tr>
<th>Correlation coefficient Animation Students</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 1: Occlusion Objects</td>
<td>0.99</td>
<td>0.94</td>
<td>0.89</td>
<td>0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>Section 2: Locoramps</td>
<td>0.78</td>
<td>0.76</td>
<td>0.69</td>
<td>0.72</td>
<td>0.74</td>
</tr>
<tr>
<td>Section 3: Digital Cinematography</td>
<td>0.78</td>
<td>0.78</td>
<td>0.89</td>
<td>0.89</td>
<td>0.84</td>
</tr>
</tbody>
</table>

Compared to the diving group, the animation students returned a higher correlation coefficient in all sections. Due to their area of study, this group has a high level of visual understanding and familiarity with digital imagery, which could explain why their score in the digital cinematography section (0.84 average) was significantly higher. The occlusion objects section returned a high result (0.95 average) which could be due to the animators tacit understanding of improved 3D depth cueing in the images caused by the occlusion objects.

Table 9: Correlation Coefficient: Maritime Archaeology Students

<table>
<thead>
<tr>
<th>Correlation coefficient Archaeology Students</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 1: Occlusion Objects</td>
<td>0.99</td>
<td>0.95</td>
<td>0.99</td>
<td>0.96</td>
<td>0.97</td>
</tr>
<tr>
<td>Section 2: Locoramps</td>
<td>0.87</td>
<td>0.92</td>
<td>0.89</td>
<td>0.80</td>
<td>0.87</td>
</tr>
<tr>
<td>Section 3: Digital Cinematography</td>
<td>0.87</td>
<td>0.73</td>
<td>0.87</td>
<td>1.00</td>
<td>0.87</td>
</tr>
</tbody>
</table>
The maritime archaeology students returned the highest correlation coefficient in each section, with a 100% match to the model answers in four of the questions (occlusion Q1 and 3, *locoramps* Q2 and cinematography Q4). This group was the most familiar with standard industry methods of displaying shipwreck data from multibeam sonar and would be the participants most likely to recognise the impact of *occlusion objects* on displaying point clouds in this field. The high results in section 2 suggest that the improved level of detail achieved by the *locoramps* method was recognised when compared to industry standard methods. An equally high result is returned in section 3, suggesting an overwhelming preference for moving images compared to stills.

In all sections of the survey completed by each participating group the correlation coefficient exceeds 0.5 for all questions in each section, ranging from 0.63 to 0.99. This reveals a close match between the author’s model answers for each section and those submitted by the participants. Therefore, it can be concluded that the results are statistically significant.

### 11.5.3 P-Value: The Play of Chance

The *P* value of the results data was calculated to check for the play of chance or probability. Following the laws of probability, each answer to each question would have an equal likelihood of being selected if chance was the only factor. I.e. if the answers were randomly chosen. When the *P*-value is very small, e.g. *P*<0.001 (which equates to 1 in a thousand answers occurring by chance) then we can conclude that the results are statistically significant and could not have occurred by chance.

The *P*-Value calculated for all questions in each section for each participating group was found to be in the range *P*<0.001. It is therefore extremely unlikely (less than 1
result in 1,000) that the results occurred by chance. Therefore the P-value results from the survey are statistically significant.

11.6 Summary
The online survey results from the three participating groups were subjected to statistical analysis that compared the results to a set of model answers. The p-value was calculated (P<0.001) and showed that the results could not have been produced by chance. The correlation coefficient showed a strong positive agreement between the model answers and the participants’ responses. The percentage of agreement with the first choice model answers was also very high. Each of the tests provided evidence that the results were statistically significant.

The occlusion objects section of the survey (section 1) produced the strongest results. This section illustrated the difference between standard industry methods of displaying point cloud data compared to the application of occlusion objects. This suggests that occlusion objects make a significant improvement to the viewers’ appreciation of the image.

The second section displayed images rendered using occlusion objects and the addition of locoramps to one of the images. The results in this section showed a strong preference for the image with locoramps but not as high a correlation as in section 1. This could be due to the dramatic difference that the use of occlusion objects makes to the viewers’ understanding of the image when compared to industry standard methods. I.e. significantly improving the gaps between points perceptual problem and therefore reinforcing gestalt principles of visual perception as described in chapter 9. The addition of locoramps improves the differentiation of smaller details
on the wreck data but it is possible that this is a more subtle change than the introduction of occlusion objects; therefore the impact is less obvious to the viewer. In hindsight an extra section could have been added to the survey in which locoramps were introduced independently of occlusion objects in order to assess their impact in isolation.

Section 3 of the survey compared still images of the wreck with short movies of the same details. Once again the results showed a significant preference for the moving images, thus supporting the premise that the application of digital cinematography reinforces the viewers’ perception of the visualisation.

The next chapter describes the implementation of occlusion objects, locoramps and digital cinematography in a number of real world examples.
12. Validation in Real World Applications

To triangulate the evaluation process, two further methods were employed. Expert users were identified in the fields of recreational diving, maritime heritage management and marine salvage. Each expert was asked to complete the interactive survey and answer questions utilising a semi-structured interview method (Foddy, W 1994). The open questions allowed the individual experience of each interviewee to be explored.

In addition to the interviews, the adoption of occlusion objects, locoramps and digital cinematography in real world scenarios was reviewed as the third element of the evaluation triangulation process.

12.1 Expert User Interviews

The interviews were based on a series of questions that enquired about the subject’s experience using multibeam sonar (if any) and in what context.

There are three sections to the questions. The first section establishes the participants’ previous experience and awareness of multibeam data. The second section presents examples of my new methods for visualisation of the data compared to previous / current industry approaches. The third section explores potential future developments and applications of the new methods developed through this investigation. The questions were as follows:

Section 1

1. What experience do you have in using multibeam sonar data?
2. How do you use multibeam sonar data in your field of work?
3. What (if any) was your role in gathering the data?
4. How was the resulting data displayed? (on screen, printed etc)
5. What currently existing software applications for displaying multibeam data are you aware of?
6. Was the data effective in presenting useful information for your requirements?

The interactive survey tool is introduced and the participant is asked to complete the survey. This is followed by a demonstration of WreckSight software showing multibeam data in an interactive environment using my new visualisation methods.

Section 2

7. How does WreckSight compare to other tools that you have seen?
8. With Wrecksight, is it easier to understand the wreck data?
9. Is this a fair comparison?

10. Supplementary questions about Wrecksight

Participants are shown the supplementary questions and answer those that they feel are relevant to their own experience:

• How does the presentation of data in WreckSight compare to other methods that you have seen?
• Which features do you consider to be the most useful in your field of work?
• Which features are the least useful?
• What would be the implications of using WreckSight for surveyors in the field?
• What are the opportunities to use WreckSight for public dissemination of data?

Section 3

11. What new features would you like to see in the future?
12. Do you have any additional comments?

The interviewees were selected to represent the industries which were considered to be most likely to have a practical use for 3D visualisation of shipwrecks. These were:

- **Recreational Diver Applications**: A dive boat skipper based in Orkney with many years experience of recreational diving on the wrecks at Scapa Flow.
- **Heritage Applications**: A maritime archaeologist at Historic Scotland with responsibility for management of underwater heritage sites.
- **Salvage Applications**: A commercial marine salvage professional working with Mammoet, a large Dutch salvage contractor.

The interview transcripts are available in Appendix A and are summarised and evaluated here with quotes presented in italics:

**12.1.1 Recreational Diver Applications**

The dive boat skipper had no direct experience of gathering multibeam sonar data but had been involved in attempting to locate wrecks with sidescan sonar in the past. He also took part in the trial of Wrecksight Scapa Flow, using it to brief divers before they commenced a dive and observing how they used it post-dive to discuss their experiences. He commented that divers were used to referring to printed images from the dive magazine “wreck tours” which used artist’s impressions of the wrecks (see chapter 3.3) but Wrecksight was the first time that they had access to 3D images that were interactive. His answer to question 6, *Was the data effective in presenting useful information for your requirements?* made a direct comparison to an example of artist’s impressions:
“It was very popular with the groups on board. Divers usually stay with us for a week. They mostly turn up with Rod’s pictures (Rod MacDonald author of Dive Scapa Flow) (McDonald 2000) and were really happy to see something more accurate. They used it before the dive then were back on it afterwards talking about their dives.”

He observed that the most useful feature was the interactive nature of the application, allowing the user to move around the wreck to see “different features”. In addition, the ability to place a shotline was seen to be very useful. Recreational divers at Scapa Flow may dive a wreck on numerous occasions during the week and knowing were the shot line would lead them was considered to be a valuable feature. A feature suggested for the future was the addition of contextual data alongside the shipwreck image:

“I think the divers would like to have some of the information about the wreck that they get in the magazines. So they could see what the ship looked like before it sank and other information like that.”

This would be relatively simple to implement. The addition of archive photographs, diver videos, photographs and annotations could enrich the user experience substantially. The skipper’s final comment was to suggest that the peripheral wrecks around Scapa Flow could be included in the application e.g. the James Barry, a sunken trawler at 40m, which is a very popular dive site regularly visited by diving groups at Scapa Flow.

12.1.2 Heritage Applications

The maritime heritage manager had some direct experience of projects using multibeam sonar survey techniques in Scapa Flow (ScapaMap) and the Sound of Mull Archaeological Project (SoMap). His role in gathering the data was as project
manager, directing surveyors then providing archaeological interpretation for heritage management purposes. His observations on the effectiveness of using multibeam data identified that quality was reliant on the collection method and technology used:

“There is a feeling that the archaeologists sector is just beginning to discover the potential and surveyors are just beginning to understand how it can be applied to archaeology and what the specific need of our field are. The quality is variable. At the very high end, like the high resolution stuff you are doing (ADUS) but if the wrong bit of equipment is used in the wrong way, not such good results”

Interactivity was again mentioned as a key factor and advantage when using Wrecksight:

“… in the Wrecksight versions I have used, interactivity is a huge advantage to interrogate specific aspects of the image, and that’s quite important from our perspective of understanding what is on the seabed.”

He also observed the problem with creating artificial surfaces from point cloud data in standard industry tools:

“I find the imagery very, very easy to understand. The distinction between the structure and the seabed is very clear. Yet you haven’t lost the detail because you have still got that point cloud material there. The imagery doesn’t lose the detail of what’s there. Whereas with Fledermaus and others, you are putting an artificial surface over the points. I think you are losing a lot of that (detail).”

The features considered to be the most useful reiterated the point about interactivity and also commented on the implementation of occlusion objects:
“The ability to move around under your control, rather than being flown round with someone else’s perception of what you should see. I found the use of the occlusion layers (objects) quite helpful because with point clouds alone it can be quite difficult to understand it.”

However he commented that the having the ability to switch off the occlusion object was a good feature since occlusion objects could contain human error and therefore distort the data. Having the option to toggle occlusion on and off was seen to be positive. A further observation, that some skeptics might see the visualisation as “too good to be true”, was interesting in that it could imply that progress made by implementing locoramps and occlusion objects, enhanced by digital cinematography was such a significant improvement on standard methods that it was difficult to accept by some:

“I think it’s a real step forward. What would be nice to see? To win over some of the skeptics because they think it’s too good to be true would be analysis of the results. So I guess the PhD (this thesis) would help by putting it all into an academic context to test the results.”

12.1.3 Salvage Applications

The marine salvage professional had extensive experience as a Naval Architect working with Mammoet Salvage. He was closely involved in the Campania project described in the previous chapter. He describes his experience of using multibeam sonar as “almost nil”, however, the experience he describes is directly relevant to this investigation:

“…involvement in a number of wreck surveys and a small number of surveys in locating a wreck and lost objects”
He describes the use of multibeam sonar data in pre and post salvage situations as a means to understand the wreck to direct divers on site and also to communicate the situation to third party interests:

“It’s only used if a wreck (object) is fully submerged and we need a way to visualize the object and/or show the actual situation. Visualization of object is sometimes needed to show the actual situation to our own divers and relevant authorities, owners and insurance companies. Secondly it’s sometimes used for verification that wrecks and/or objects is/are removed to full satisfactory of (local) authorities, owners and/or insurance company.”

His role in gathering the data was in setting up the survey projects and verifying that the collected data was actually useful. When multibeam sonar data was used to present data to clients it was found to be “most effective”. Although there were some situations were conditions or equipment failure had prevented accurate data from being collected.

Comparing Wrecksight to other tools he states:

“It’s one step ahead. All other tools used for survey presents data in the same 2D pictures which is not always understandable for 3rd parties or “non insiders. With Wrecksight it is/was much easier to understand the “wreck”. A clear picture/image will tell you more than a thousand words! In the “California” situation the images revealed much more damage than expected, and was found with previous diving inspections.”

He describes the most useful features as the ability to move around the data interactively in 3D without the need for specialist knowledge of the data. This simplicity of use presents opportunities for wider dissemination of shipwreck data:
“Environment will be more and more important in the future therefore “people” will be more and more curious what’s down there and what’s going on. If in the near future these images can be produced more easily in a fancy for common public more understandable format it will be more often used not only by salvage companies but most probably also by other parties”

Suggestions for future features included options to export the wreck data into other software formats for other forms of presentations (e.g. print). The key suggestion was to link the data format to USBL (Ultra-Short Base Line) tracking systems. USBL is usually used to track the position of ROVs when investigating deep water sites.

In summary; all three of the expert users interviewed described positive experiences of using occlusion objects, locoramps and digital cinematography in the Wrecksight application. Each found advantages over other methods of shipwreck visualisation that they had previously used, whether artists illustrations or standard industry software. All the interviewees had suggestions for improving or adding new features to the visualisations. Interactivity was commonly seen as a key feature. The full interview transcripts can be found in Appendix A, 14.2.

12.2 Other Real World Applications

Following the completion of the HMS Royal Oak and SS Richard Montgomery projects, further opportunities to test, refine and consolidate the 3D visualisation methods were presented. One of these involved the survey of a sunken Russian Nuclear submarine.

12.2.1 Environmental Hazards: B159 Russian Nuclear Submarine

The November class, Russian Nuclear submarine B159 (formerly K-159) was decommissioned from active service on 30th May 1989 and laid up at Gremikha, a naval base in the Barents Sea, Arctic Circle. The submarine’s twin nuclear reactors
were not removed or de-fuelled and the vessel remained there with little or no maintenance for 14 years.

On 30th August 2003, the submarine was under tow from Gremikha to the Polyarny shipyard for dismantling when it broke free from its towing harness and sank in 250 metres of water. Of the ten crew members on board, one survived and only two bodies were recovered. The remaining seven bodies are likely to be still onboard alongside approximately 800 kilograms of spent nuclear fuel with a radioactivity level of 750 curies per kilo (Bellonia 2003).

The Commander of the Northern Fleet at the time was Admiral Gennady Suchkov. He was subsequently court marshaled for criminal negligence leading to the death of the submariners. The Russian Federation undertook a video survey of the wreck in 2004 but lost their Tiger ROV during the process.

In June 2007, ADUS joined an international G8 funded survey expedition led by the UK Ministry of Defence, at the request of the Russian Federation. The survey took place between 28th June and 4th July 2007, from the NATO survey vessel Alliance (Figure 12.2). Due to the depth of the wreck, (250 metres) the NATO Submarine Rescue Service Intervention ROV (NSRS IROV) was procured for the project.
The survey successfully gathered multibeam sonar data from the submarine wreck. The resulting 3D visualisation showed the submarine sitting upright on the seabed with a six metre section of its stern missing. The site of the wreck was an area of significant activity during the cold war period. Both NATO and Russian seagoing vessels patrolled the Barents Sea, effectively curtailing fishing in the area which had previously taken place for centuries. The direct results of this were seen in some of the survey data. When the IROV was close to the wreck, its lights and propulsion noise attracted large shoals of fish. This can be clearly seen in Figure 12.3 where the sonar device has picked up reflections from the shoal. This caused some delay during the survey since the IROV had to be parked on the seabed with its lights off until the fish dispersed.

The final 3D visualisation shows the wreck on a pitted seabed with two of the floatation pontoons nearby. Damage to the hull of the vessel can be clearly seen (Figure 12.4), suggesting considerable impact from the floats as the submarine sank. In the wider area view (Figure 12.5) it is possible to see crater like deformations in the seabed. These were initially considered to be damage from cold war depth charges. However, these features can also be found in areas of UK waters were
there is no history of depth charge use. It is therefore most likely that they are caused by gas emissions through the seabed sediment.

“Towards the stern of the wreck, raised sediment ridges are apparent on both sides of the hull (Figure 10.6). This is evidence that the submarine impacted the seabed stern first then rotated forwards along the keel line, possibly breaking of the stern section under the sediment. The survey data shows no discernable major distortion of the hull although specific damage to parts of the outer casing is evident. This implies that the internal pressure hull will be in reasonably sound condition. If further surveys prove to be the case, it is possible that the vessel could be lifted in one piece.”

Martin Dean, B159 Survey report for the Ministry for Defence.
In Figure 12.4, the damage to the starboard side of the hull can be clearly seen. The separate locoramps for the submarine and the seabed help the viewer to see how the wreck has displaced silt on the sea floor.

Figure 12.5 shows a wider area view of the wreck site. The displaced seabed material along each side of the submarine’s hull appears to be higher towards the stern. A semi-circular spray of silt is also visible in front of the bow.
During the survey operation, the NSRS IROV recovered the small Tiger ROV previously lost by the Russian Navy. On recovery, the B159’s pennant was found to have been caught in the ROV’s propulsion mechanism. The pennant was removed, cleaned and presented back to representatives of the Russian Navy on board Alliance (Figure 12.7).
The final report and 3D visualisation were presented to representatives from NATO and the MOD at Greenock in August 2007. At the date of this document\textsuperscript{18}, no further action has been taken by the Russian Federation to recover the B159 or the bodies of the crew believed to be still on board.

The MoD initially embargoed the release of images from the 3D visualisation of the B159 although the Russian Federation did publish them internally. More recently in 2010, WIRED magazine was granted permission by the MoD to publish some images alongside an article “Grounded Submarine Photographed With Sonar” in April 2010 (WIRED 2010).

The B-159 project provided an opportunity to test the occlusion objects, locoramps and digital cinematography methods on multibeam sonar data gathered at much greater depths than previously attempted. Some problems were encountered during the data editing stage due to issues with tracking the ROV movement on separate passes over the submarine wreck. However, this was resolved with a minor modification to the visualisation process resulting in the effective application of the novel methods described in this doctoral study. The project provides evidence that these methods are not limited to shipwreck data gathered from surface mounted sonar equipment but are equally effective with much deeper targets. Depth is not a restriction.

\textbf{12.2.2 Research and Development with Sonar Manufacturer Reson}

The ADUS team has provided R&D support for Reson, a leading manufacturer of multibeam sonar equipment, and has carried out trials with the company to test and refine their products. In May 2009, testing of the Reson 7125 sonar head was carried out using known shipwrecks in the Sound of Mull, Scotland.

\textsuperscript{18} December 2010
High resolution data from the wreck of the SS Breda in Ardmucknish Bay near Oban was gathered and a 3D visualisation using occlusion objects and locoramps was produced (Figures 12.8 and 12.9). This is being used by Reson to demonstrate the capabilities of their 7125 system. A short video from the visualisation is available on Reson’s YouTube page at http://www.youtube.com/watch?v=ib8m_jiuURU and in Appendix B, 15.4.

Further R&D is in progress to identify and resolve issues deploying Reson’s new equipment on ROVs. The use of ROVs extends the potential market for high resolution 3D visualisation of shipwrecks to much greater depths, reinforcing the findings from the B-159 project.

The SS Breda project produced higher density point cloud data than previous work. This provided an opportunity to further explore the application of locoramps to separate and display detail on the decks of the wreck. Since the wreck is accessible to recreational divers, it was possible to check the authenticity of the data by exploring the wreck first hand and identifying features that were made visible in the visualisation. The visualisation was used to plan dives by members of Dundee
University Sub Aqua Club (DUSAC) to explore sections of the wreck lying on the seabed on the port side. Due to low visibility on the site, divers who had prior experience of diving the wreck (including the author), were unaware of the existence of this wreckage on the seabed until it was made apparent in the visualisation. Visibility on the wreck is usually about 5 metres so the scattered wreckage would only become apparent if the diver descended off the bow of the wreck to the seabed and swam towards it. The results of this project provided further validation of the author’s novel visualisation methods and evidence of their usefulness in recreational diving.

12.2.3 Articles and Press Coverage

During this investigation, as the new visualisation methods were developed and tested in real world scenarios, the author and colleagues at ADUS attended conferences and wrote articles to present early findings. This dissemination included trade press in the salvage industry, diving related magazines and the media in addition to more academic publication, which are listed in chapter 13.

A selection of publications:

• *Picture Perfect: The Fallen Oak* Scotland on Sunday, Sept 24 2006 p3 News Feature
• *Scapa Flow in 3D*, Diver, January 2007, Volume 32 No 1, p32 – 36. ISSN 0141-3465
• *The Sinking of HMS Royal Oak*, News Item, BBC News at One/ News at Ten, June 2007
• *Scapa Flow Wrecks* DYK (Denmark) and DYKKING (Sweden) July 2007, p28-33
• *WreckSight: The Sonar View of Shipwrecks*, Diver Magazine (USA) August 2007 Vol 33 No 4. p32 – 41. ISSN 0706-5132


• *Scapa’s Forbidden Wreck*, Dive Magazine, Nov 2009, p47 - 52

• *Unraveling the Mystery Below*, Marine Technology Reporter, Front cover image and article. Jan/Feb 2010 p40-43 ISSN 1559-7415

• *Grounded Submarine Photographed With Sonar*, WIRED Magazine, May, 2010 p20

• *Breda Uncovered*, Scottish Diver. Front cover + article. July 2010 p20 – 21 (Figure 14.9)

Figure 12.9 Scottish Diver Magazine featuring images of the SS Breda
Presentations at diving and salvage related conferences:

• Hydro International 2008, USA
• BSAC Diving Officer’s Conference 2008, London UK
• Reson User Group Conference, 2008, Moscow, Russia
• ScotSac Conference 2008, Oban, Scotland
• Dive Ireland, 2008, Belfast, Northern Ireland
• ITS Conference 2010, May, Vancouver, Canada
• Festival of the Sea, May 2010, Oban, Scotland

Dissemination of the research at conferences and public events provided valuable opportunities to gain feedback about the research at various stages of development. The feedback was consistently supportive of the developments in 3D visualisation of shipwrecks although at early stages there were some skeptical comments questioning the authenticity of the data. This attitude raised its head again recently when Wired magazine published a story about the B159 project (May 20th 2010 p20). The magazine’s online forum hosted a lively debate, here is a short excerpt:

“I process sonar data and if that is an image based on real soundings I will eat a school of Atlantic Cod. I think someone had too much time on his hands and a fancy computer on April 1.”

Hunter Apr 6th 2010

“Hunter, we know this is just your attempt to get a bunch of free fish.”

Dave Apr 7th 2010

As the work became more widely published and adopted by various communities (diving, salvage and heritage) its authenticity was accepted and feedback became more focused on suggestions of new functionality in future developments. On the whole, the process of dissemination served to validate the research and approaches taken.

19 Available at http://www.wired.co.uk/magazine/archive/2010/05/start/grounded-submarine-photographed-with-sonar
12.3 Summary

The expert user interviews provided an insight to the opinions of professionals representing the recreational diving, maritime heritage and marine salvage industries. Each had their own requirements for 3D visualisations of shipwrecks and a varied experience of industry methods was evident.

The recreational dive skipper compared the use of the interactive rendering provided by Wrecksight to the diver’s standard method of using artist’s impressions and illustrations from the diving press. He highlighted the advantage provided by being able to explore the 3D wrecks interactively and also commented on the greater accuracy in Wrecksight. The option to place a shotline on the wreck data was seen as a positive feature to help divers when planning their dive.

The maritime heritage manager had more extensive experience of working with multibeam data and was able to make a direct comparison with current industry methods of displaying the data. His comments recognised the use of occlusion objects as a benefit, so long as they could also be switched off when required. He also noted that the use of locoramps added “quite a lot” to the viewer’s perception of the wreck image. A particular point was his observation that the standard industry method of draping a surface mesh over the point cloud tends to “lose a lot of detail” compared to the author’s method of displaying the point cloud with occlusion objects. The interactive nature of Wrecksight was also recognised as being a positive means of improving understanding of the wreck data.

The marine salvage expert had experience of using multibeam data for wreck removal and searching for lost objects underwater. He commented that in the example of the California wreck, the 3D images using the author’s novel visualisation methods provided much more information and detail than previous diver surveys had
identified. The images revealed far more damage to the wreck than had been expected. He described future uses of the methods as likely to be beyond the salvage of wrecks, suggesting that the visualisations could be used by the general public to view important underwater sites.

The B-159 project provided further opportunities to evaluate the use of occlusion objects and locoramps with data gathered via the deployment of a remotely operated vehicle. The data gathered, presented problems in the post-processing stage but the final visualisation was effective in communicating the condition of the wreck as well as providing evidence to support theories on how it may have sank. The depth of the wreck was considerably deeper (250m) than previous work and proved that the novel visualisation methods are not restricted to surface mounted technology. Data from deeper targets benefit from the application of occlusion objects and locoramps.

Working with Reson to evaluate the performance of their latest technology led to the production of even higher resolution shipwreck data. The visualisation of the SS Breda wreck is now being used to promote the company’s capabilities as well as a tool to explore parts of the wreck that were previously unknown to many recreational divers. Again, the implementation of occlusion objects and locoramps improved the representation of the data, further validating these methods in shipwreck visualisation.

Dissemination of the work through articles in the recreational diving and salvage press suggests that these industries have recognised the value of the work and its impact on their communities. Interest in the work has led to invitations to present papers at diving, salvage and heritage related conferences around the world. This suggests that the work is gaining wider recognition and acceptance, thus providing
further validation of the novel visualisation methods developed through this doctoral research.

Three methods of evaluation were adopted; analysis of results from the interactive survey, expert user interviews and validation through real world projects. Cross-correlating the result from this triangulated approach, produced evidence that the implementation of *occlusion objects*, *locoramps* and digital cinematography improve understanding of 3D shipwreck data in the three communities that participated in the evaluation.
13. Conclusion

This chapter summarises the research approach taken during this investigation and reviews the key research findings, which the research questions have addressed. Implications for future work are discussed and finally, a selection of academic publications resulting from the study are described.

13.1 Summary of Research Undertaken

This doctoral investigation centred on the 3D visualisation of historic or environmentally significant shipwrecks. Using data from a number of case studies, the author set out to identify the key characteristics of displaying point clouds from multibeam sonar surveys with a view to developing visualisation methods that improve understanding of the data. A review of academic literature and practice revealed that very little work has been done in this area to date, suggesting that a gap in knowledge in the subject domain exists.

Analysis of current methods of visualising shipwrecks revealed that the three main fields using various forms of shipwreck visualisation; recreational divers, maritime heritage and marine salvage could benefit from improvements in the available 3D visualisation methods. Where multibeam sonar data was being used in salvage and heritage, the wide variance in the quality of survey data produced meant the potential benefits of 3D visualisation had not yet been fully realised. Analysing current industry methods provided insights into the key characteristics of point clouds and problems inherent in displaying the data. The key research questions were therefore formulated to focus the study on identifying problems in displaying the data and developing potential solutions.
The case study shipwreck data was provided by colleagues at Advanced Underwater Surveys (ADUS), whose pioneering work in gathering very high resolution survey data provided a unique opportunity to experiment with visualisation methods. A cyclical, multi-method approach was adopted in which methods developed in one case study experiment were applied and developed further in the subsequent case studies.

13.2 Answering the Research Questions

The extent to which each question was addressed is described, starting with question one:

• What are the most significant factors in displaying point cloud data of shipwrecks from multibeam sonar?

Multibeam sonar data from the survey of the Royal Oak was viewed in Fledermaus using rendering methods from the standard industry approach. The “gap between points” problem was identified. This is where background features of the wreck or surrounding seabed are visible between foreground points; therefore confusing the viewer’s perception of the shipwreck’s structure. The standard method to deal with this is to drape a polygon mesh over the points. While this does stop the viewer seeing through the data, it also conceals details in the wreck data.

Another key problem is the arbitrary use of colour in the rendering of shipwreck data in standard software (e.g. Fledermaus). Multibeam sonar data contains no inherent colour information since the data is produced by sound. Only positional data is recorded, therefore colour is assigned during the visualisation process. The accepted method of assigning a rainbow colour ramp to the data provides only depth information which is inconsistent when applied to different datasets by different users. For example, the colour red can be used to represent data at a depth of 15m
to 20m in one dataset but can be used to represent 30m to 45m in another. In any case, the colour bears no relation to specific features on the shipwreck.

These two characteristic problems were identified as the focus of the second and third research questions:

- Which current methods of visualising shipwrecks from multibeam sonar can be improved?

The method of using polygon surfaces to replace point cloud data as a solution to the "gaps between points" problem was identified as an area that could be improved. Experiments using data from the Royal Oak sonar survey, led to an alternative solution to this problem. The development of occlusion objects allowed the detail in the point cloud data to be preserved while restricting the visibility of distant points so that they don’t appear in the foreground thereby confusing the viewer’s perception of the structure of the wreck. Occlusion objects offer a simple but effective solution.

The third research question addresses the issue of point cloud colour:

- Can the use of aesthetically considered colour improve the rendering and display of shipwreck data?

Data from the SS Richard Montgomery sonar survey was used to explore the problem of assigning colour to point clouds. As stated earlier, the standard industry method is to assign a single banded, rainbow colour ramp to the point cloud with each colour band representing depth. The author developed an alternative method that first segments the data into specific features of the wreck then assigns an interpolated colour ramp that is oriented to align with each feature. Multiple ramps
are used and are assigned locally to specific features. These locoramps (locally oriented colour ramps) allow small details on the wreck to be highlighted and made more visible to the viewer. Locoramps allow sensitive interpretation of the shipwreck data by providing subtle changes in colour that are relevant to local features on the wreck.

A secondary research question emerged during the study:

- What effect does the application of digital cinematography have on the perception of shipwreck data?

Through the investigation it became apparent that still images of the visualised shipwrecks did not appear to provide as much information to the end user as moving images. Where the survey data produced incomplete or lower resolution point clouds, by simply moving the virtual camera over the data it was possible to improve the viewer's perception of indistinct features. This can be explained by gestalt theory, in which visual perception favours patterns in data that appear to be grouped or aligned. Therefore, by slightly moving the camera, a better understanding of the spatial relationship between points can be established.

This effect was evident in pre-rendered movies e.g. The Fallen Oak, in which debris on the seabed close to the Royal Oak was easier to identify as the camera slowly tracked past. By adding interactivity to the 3D visualisation, the control of the camera can be placed in the hands of the viewer. This was achieved through development of the Wrecksight software application. Wrecksight was designed to implement occlusion objects, locoramps and digital cinematography in an interactive viewer and has been used by the three main user groups.
To evaluate the effectiveness of using occlusion objects, locoramps and digital cinematography in the visualisation of shipwreck data, a triangulated approach was taken. The interactive survey tool used with recreational divers, animation undergraduate students and maritime archaeology postgraduate students produced data which, on analysis, proved statistically significant.

The P-Value was established as $p<0.001$ illustrating that the results could not have been produced by chance. The correlation coefficient was also calculated to compare the participants’ level of agreement with a set of model answers that rated the author’s new methods higher than standard industry methods. The percentage of first choice agreement with the model answers was also calculated. The results showed that the participants in each group expressed a clear preference for shipwreck visualisation that used occlusion objects, locoramps, and digital cinematography by rating images in the survey rendered using these methods, higher than others which did not.

The second stage of the evaluation triangulation was by peer review through interviews with expert users from the diving, heritage and salvage industries. The interviews revealed a common agreement that the novel methods (occlusion objects, locoramps and digital cinematography) combined with interactivity were of significant benefit to end users in each field. Finally, a review of real world projects that exploited these novel methods in the field was undertaken.

### 13.3 Impact

The impact of the outcomes of this investigation can be measured in the adoption of occlusion objects, locoramps and digital cinematography in the three industries identified.
Feedback from representatives in the key industries continues to support the development of new features in the Wrecksight application in the future. In the salvage industry, working with the company Mammoet on the *New Flame* wreck off Gibraltar, the visualisation techniques were used in pre-salvage planning, risk assessment and again post salvage, when the work was complete to prove to the Gibraltan and Spanish Governments that the work had been carried out to their specification.

Sports divers in Scapa Flow use the visualisations to plan their dives and estimate distances and duration. Post dive, they use the WreckSight software to map where they had been to and what they had seen on the wreck dive. Similarly, archaeologists mapping the wreck of the *Campania* use the application to plan their route in very low visibility, marking out distances between recognisable features on the wreck to aid their navigation.

In addition to adopting the use of *occlusion objects, locoramps* and digital cinematography techniques as previously described, the salvage and recreational diving industries have supported the dissemination of the novel methods through publication of early stage outcomes at salvage, heritage and diving related conferences (see chapter 12.2.3). Interest from publications such as *Tug and Salvage International*, and *Diver Magazine* has steadily increased as 3D visualisation projects were completed. The multibeam sonar manufacturer Reson also uses the author’s shipwreck visualisation images in their marketing and advertising materials as examples of best practice using their technology.

Publication of the outcomes from this investigation has also been sought via academic routes with a number of international academic conferences accepting papers and presentations at various stages of the process. These are listed in 13.5.
13.4 Summary and Future Work

In summary, the author proposes that the development of occlusion objects, locoramps and the adoption of digital cinematography techniques in the 3D visualisation of shipwrecks from multibeam sonar represents the “contribution to new knowledge” in this investigation. The evaluation and validation of these techniques, as described in this thesis, supports the author’s proposal that they improve the viewer’s perception of the shipwreck data.

At the time of writing, new opportunities for the application of high resolution visualisation of subsea structures are becoming apparent. The catastrophic events befalling the Deep Water Horizon oil rig in the Gulf of Mexico in 2010 and the expansion of offshore and sub sea renewable energy installations suggest that energy, oil and gas are potential areas of application for improved 3D visualisation.

The technical challenges that require further work include the investigation of methods to automate or semi-automate the construction of the occlusion objects. Early tests using cloth simulation tools were limited by computing resources and time but further experiments in this area should be conducted. An alternative method would be to develop techniques to switch off the visibility of sets of point clouds as a function of their position in relation to the camera.

The recreational diving community could benefit from the inclusion of other media in the Wrecksight application. User annotations, photographs and video clips could be incorporated along with archive material illustrating the ships history. This would also have applications in the maritime heritage field; Wrecksight could be developed as an interactive interface to museum exhibits of artifacts gathered from historic wreck sites, thus virtually re-uniting the artifacts with 3D images of the wreck itself.
Locoramps could be further developed to allow the user to edit colour interactively. This would hand over increased aesthetic control of the visualisation to the end user. As the survey targets increase in scale (e.g. Deep Water Horizon oil rig) and the data collection methodologies improve, the amount of data gathered in a sonar survey will increase significantly. Therefore it may be necessary to add functionality to further segment and display the data within WreckSight. To achieve this, levels of detail could be controlled by the end user through selective sampling of the data.

The case studies presented in this thesis are examples of shipwrecks with metal hulls. One wooden hulled shipwreck was surveyed and visualised as part of the RASSE project (Rapid Archaeological Site Survey and Evaluation) led by St Andrews University. The wreck was of the Stirling Castle, a flagship of Samuel Pepys navy which sank at Goodwin Sands in the South West English coast. Historic wooden wrecks tend to have deteriorated more than their metal hulled counterparts. This is partly because they tend to be much older and the material breaks down more quickly. The resulting sites are characteristically lower lying on the seabed and can be partly buried by silt or sand. Further work needs to be carried out to refine the use of occlusion objects and locoramps to enhance the visualisation of the wrecks of wooden ships.

The role of the author as artist in the development of the visualisations is also a topic for future investigation. Although not a focal point of this study, tacit knowledge gained through creative practice informed the design of the 3D visualisations. In particular, the choice of colour and shading implemented by the use of locoramps was informed by this tacit knowledge. Further study could develop understanding of how art and design methodologies can be applied to wider areas of visual research.
Early experiments to automate the construction of occlusion objects using cloth simulation techniques were unsuccessful. Simulated cloth could be draped inside the point cloud data to create an interior surface that closely resemble the shape of the wreck therefore increasing the accuracy of the occlusion object. However, as technology and algorithms for cloth simulation improve, this area could be revisited in future.

Alternative applications for locoramps could also be investigated. For example, the archaeological study of cliff faces may benefit from the application of locoramps oriented to emphasise the visibility of surface details. This method could also be applied to the surfaces of laser scans of ancient artifacts to enable close analysis changes in surface details. The locoramp method would require further development to be effective at the high level of detail evident in small artifacts.

13.5 Academic Publications

A selection of academic publications and exposition from various stages of the investigation:

Screenings of “The Fallen Oak”

- Siggraph Digital Eyes Exhibition, San Diego. USA. 2007
- Siggraph Travelling Art Show, (various venues USA and Europe) 2007-2009
- Siggraph Computer Animation Festival 2007
- Scapa Flow visitor centre, Lyness, Orkney, 2008
- 25th annual Unicaja Competition 2009 (Finalist): International Biennial of Scientific Film, Malaga, Spain.

Academic Conferences, Events & Papers

- Using NPAR to Reveal “The Swan” Siggraph 2005, Los Angeles, USA. Research Poster


• **High Resolution Imaging of the German Fleet at Scapa Flow, CAA 2007 conference, Berlin, Germany.**


• **Alt-W: 10 years of Scottish Digital Culture.** 2008. Exhibition, New Media Scotland. CCA, Glasgow

14. Appendix A

14.1 Literature Review Searches

Keyword Searches

Example keywords and combinations with results from the ACM GraphBib database:

<table>
<thead>
<tr>
<th>Keyword(s)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
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<td>131</td>
</tr>
<tr>
<td>Visualisation + point cloud</td>
<td>133</td>
</tr>
<tr>
<td>Visualisation + occlusion</td>
<td>515</td>
</tr>
<tr>
<td>Visualisation + sonar</td>
<td>135</td>
</tr>
<tr>
<td>3D + Visualisation + point cloud + occlusion</td>
<td>0</td>
</tr>
<tr>
<td>3D + Visualisation + maritime</td>
<td>132</td>
</tr>
<tr>
<td>3D + Visualisation + archaeology</td>
<td>0</td>
</tr>
<tr>
<td>3D + sonar</td>
<td>5</td>
</tr>
<tr>
<td>Underwater</td>
<td>22</td>
</tr>
</tbody>
</table>

Cross Search databases:

- Science and Technology Proceedings
- SCOPUS
- IEEE Xplore
- Web of Knowledge
- Zetoc
- University of Dundee Catalogue
- British Humanities Index
- Early English Books Online
- JSTOR
- British Periodicals Collection
- House of Commons Parliamentary Papers 19th century
- OAIster (union catalog of digital resources)

14.2 Expert User Interview Transcripts

14.2.1 Maritime Heritage

Phillip Robertson: Maritime Archaeology Officer; Historic Scotland

Section 1

Question 1: What experience do you have in using multibeam sonar data?

Answer: Prior to Historic Scotland (I) was involved in a range of projects as an archeologist and project manager. Use of high resolution multibeam sonar for the purposes of archaeological surveys.

Question 2: How do you use multibeam sonar data in your field of work?
Answer: Since being with Historic Scotland, have managed two projects where multi-beam sonar survey has been used, to record wreck sites and as a means of dissemination.

Question 3: What (if any) was your role in gathering the data?

Answer: Prior to HS, I worked on two projects. One was the Sound of Mull Archaeological project. We were project managing the work with a team of surveyors who carried out the survey work itself. So we were defining the objectives and defining the range of sites that were required to be surveyed and to a certain extent, defining the quality of the survey work, although we relied heavily on the surveyors’ technical expertise. They also processed the raw data. I did a lot of the post-processing work and learned a lot doing that. I then interpreted the data for archaeological purposes but not at a technical level. Here (HS) I have been one step back from the work, interpreting and understanding what it’s telling us as heritage managers.

Question 4: How was the resulting data displayed? (On screen, printed etc)

Answer: On screen then printed later for the Sound of Mull project and probably the same for the project at Scapa Flow.

Question 5: What currently existing software applications for displaying multibeam data are you aware of?

Answer: Fledermaus

Question 6: Was the data effective in presenting useful information for your requirements?

Answer: If we look at Scapa Flow and the Sound of Mull, with the three dimensional wreck structures. Realistically we couldn’t survey them without it. It would just be too expensive to tackle in any other way. I’m not saying it’s the be all and end all, it’s just a tool. I think archaeologists will still have a role in collecting and doing some of the more detailed seabed recording, understanding and analysis. But it’s a fantastic tool. We certainly notice the variable standards that you get from it and that’s partly due to learning on the projects. There is a feeling that the archaeologists sector is just beginning to discover the potential and surveyors are just beginning to understand how it can be applied to archaeology and what the specific need of our field are. The quality is variable. At the very high end, like the high resolution stuff you are doing (ADUS) but if the wrong bit of equipment is used in the wrong way, not such good results.

Note: The interactive survey tool is introduced and the participant is asked to complete the survey. This is followed by a demonstration of WreckSight software showing multibeam data in an interactive environment using my new visualisation methods.

Section 2

Question 7: How does WreckSight compare to other tools that you have seen?

Answer: The only other tools that I’ve used are AVI movie files where you haven’t got any control over what you are doing. I haven’t used Fledermaus much so I haven’t got that experience of flying around things interactively but in the Wrecksite
versions I have used, that interactivity is a huge advantage to interrogate specific aspects of the image, and that’s quite important from our perspective of understanding what is on the seabed.

Question 8: With Wrecksight, is it easier to understand the wreck data?

Answer: Yes, I think it is. I find the imagery very, very easy to understand. The distinction between the structure and the seabed is very clear. Yet you haven't lost the detail because you have still got that point cloud material there. The imagery doesn’t lose the detail of what’s there. Whereas with Fledermaus and others, you are putting an artificial surface over the points. I think you are losing a lot of that (detail). I suppose slightly, a scientifically cynical part of me is still questioning it because it looks so good, I can't imagine it’s really thus. Although examining the point cloud data in the examples earlier (referring to the online survey) I really couldn’t find any reason to be skeptical.

Question 9: Is it a fair comparison?

Answer: Absolutely, I don't think there is anything that’s unfair at all. Looking at the images, I quite like the colour banding for bathymetry depths mixed with the point cloud. I found that in some areas that was easy to see and interpret but without the colour banding depths (key?) perhaps it lost something. I don't think your (the author) version lost anything, in most cases it was adding quite a lot.

Question 10: Supplementary questions about Wrecksight

Participants are shown the following supplementary questions and answer those that they feel are relevant to their own experience:

10.1 How does the presentation of data in WreckSight compare to other methods that you have seen?
10.2 Which 3 features do you consider to be the most useful in your field of work?
10.3 Which 3 features are the least useful?
10.4 What would be the implications of using WreckSight for surveyors in the field?
10.5 What are the opportunities to use WreckSight for public dissemination of data?

Question 10.2 Which 3 features do you consider to be the most useful in your field of work?

Answer: The ability to move around under your control, rather than being flown round with someone else’s perception of what you should see. I found the use of the occlusion layers (objects) quite helpful because with point clouds alone it can be quite difficult to understand it. With the proviso that there is a slight concern that the extra layer of interpretation that’s been built in, by the nature of human error, there must be a certain level of information that is either distorted or lost, potentially. With the option to switch off the occlusion, that’s obviously a useful tool and means you can opt for both. That’s clearly a good thing. I haven’t used the measuring tool yet but clearly that’s an incredibly powerful and useful tool.

Question 10.5 What are the opportunities to use WreckSight for public dissemination of data?
Answer: We are going to use it for the Campania wreck, first of all to help the licence holder to explore the wreck and show divers what the site looks like. But hopefully to eventually show the public, maybe at the museum alongside other information about the ship’s history.

Section 3

Question 11: What new features would you like to see in the future?

Answer: The advances have happened so quickly that I'm astounded what has become possible. A problem has been that the data is usually very thick (heavy, large file sizes) A major step forward would be making the data sets available on the internet, as downloadable data. The problem of minimizing the file sizes while maximizing the quality of information. I think that's were the challenge is going to come. As soon as you achieve that, you make it pretty much available to anyone on any piece of equipment.

Question 12: Do you have any additional comments?

Answer: I think it's a real step forward. What would be nice to see?, to win over some of the skeptics, because they think it's too good to be true would be analysis of the results. So I guess the PhD (this thesis) would help by putting it all into an academic context to test the results.
14.2.2 Recreational Diving

Ian Trumpess: Dive Boat Operator; Scapa Flow, Orkney

Section 1

Question 1: What experience do you have in using multibeam sonar data?

Answer: I haven’t used it myself but have seen examples of it and we use sonar pictures when looking for new dive sites, mainly wrecks. The WWII submarines discovered East of Orkney a couple of years ago were typical of the images I would use on the boat. The trial version of the German Wrecks software (WreckSight) that we used with the wreck divers was more detailed than the subs. We have seen sonar pictures from years ago (ScapaMap) of the German Fleet but we didn’t get access to it for the divers so it was good to see them in 3D (in WreckSight.)

Question 2: How do you use multibeam sonar data in your field of work?

Answer: Well, the submarine pictures were pretty low spec, not very clear but they were good enough to drop a line on the subs for divers to get down to them. That’s mainly how we use the pictures, to get divers to the right spot and give them an idea of what to expect when they get there.

Question 3: What (if any) was your role in gathering the data?

Answer: None, it was (gathered) from the hydrographic survey that the coastguard does regularly to check the accuracy of the charts. They weren’t looking for the subs, just found them by accident.

Question 4: How was the resulting data displayed? (On screen, printed etc)

Answer: The sub pictures were published in some news story and after that we just copied them from the web. I asked the Coastguard office for copies but they didn’t send any.

Question 5: What currently existing software applications for displaying multibeam data are you aware of?

Answer: Just the German Wreck software (Wrecksight Scapa Flow) that you (ADUS) let us have to try out with the divers.

Question 6: Was the data effective in presenting useful information for your requirements?

Answer: Yes it was very popular with the groups on board. Divers usually stay with us for a week. They mostly turn up with Rod’s pictures (Rod MacDonald author of Dive Scapa Flow) and were really happy to see something more accurate. They used it before the dive then were back on it afterwards talking about their dives.

Note: The interactive survey tool is introduced and the participant is asked to complete the survey. This is followed by a demonstration of WreckSight software showing multibeam data in an interactive environment using my new visualisation methods.
Section 2

Question 7:  How does WreckSight compare to other tools that you have seen?

Answer:  I haven’t really seen any other software that shows wrecks. We have used sidescan (sonar) when we’ve been looking for wrecks, like the subs, but we just had printouts. So Wrecksight is really the only one. We have a file with the wreck tours from the diving mags and the divers look at them to get the background stories like how a ship sank. But the drawings in the mags are not really accurate. They are better than nothing, that’s all we had for years until this (WreckSight).

Question 8:  With Wrecksight, is it easier to understand the wreck data?

Answer:  It is easy to use and fly around the wrecks. But I don’t have anything to compare to. The divers don’t really need any help using it on the boat. I think there are instructions but we don’t really need them. It’s easy to see what the wrecks look like so I suppose it does make them easier to understand.

Question 9:  Is it a fair comparison?

Answer:  I can only compare to sidescan pictures but I think it’s fair. The sidescan is good for wreck hunting but they (the images) are not as good as the 3D pictures.

Question 10:  Supplementary questions about Wrecksight

Participants are shown the following supplementary questions and answer those that they feel are relevant to their own experience:

10.2  How does the presentation of data in WreckSight compare to other methods that you have seen?

10.2  Which 3 features do you consider to be the most useful in your field of work?

10.3  Which 3 features are the least useful?

10.4  What would be the implications of using WreckSight for surveyors in the field?

10.7  What are the opportunities to use WreckSight for public dissemination of data?

10.8

Question 10.2  Which 3 features do you consider to be the most useful in your field of work?

Answer:  Moving around the wreck so you can see different features. Showing were the shotline is on the wreck is really useful. Because it helps the divers plan their dive better. They have a good idea were they will be when they get down there.

Section 3

Question 11:  What new features would you like to see in the future?

Answer:  I think the divers would like to have some of the information about the wreck that they get in the magazines. So they could see what the ship looked like before it sank and other information like that.
Question 12: Do you have any additional comments?

Answer: I just think it would be good to have the block ships and some of the other wrecks that the divers like added. The James Barry and the F2 would be popular.
14.2.3 Marine Salvage

Han Shiet: Naval Architect; Mammoet Salvage

Section 1

Question 1: What experience do you have in using multibeam sonar data?

Answer: Almost nil. Except involvement in a number of wreck surveys and a small number of surveys in locating a wreck and lost objects.

Question 2: How do you use multibeam sonar data in your field of work?

Answer: It’s only used if a wreck (object) is fully submerged and we need a way to visualize the object and/or show the actual situation. Visualization of object is sometimes needed to show (actual) situation to our own divers and/or relevant authorities, owners and/or insurance companies. Secondly it’s sometimes used for verification that wreck(s) and/or object(s) is/are removed to full satisfactory of (local) authorities, owners and/or insurance company.

Question 3: What (if any) was your role in gathering the data?

Answer: Trying to get the project running. Checking and verifying that collected data is useful for our purposes.

Question 4: How was the resulting data displayed? (On screen, printed etc)

Answer: On screen and partly printed.

Question 5: What currently existing software applications for displaying multibeam data are you aware of?

Answer: Fledermaus, Quincy, PDS2000, Wrecksight and Autocad. Autocad is only used for visualization if raw data is processed.

Question 6: Was the data effective in presenting useful information for your requirements?

Answer: In almost all the situations when a multibeam sonar survey has been carried out the presented data was most effective in presenting the information to 3rd parties. In situations it was not possible either the equipment failed or circumstances were such that no accurate data could be collected.

Note: The interactive survey tool is introduced and the participant is asked to complete the survey. This is followed by a demonstration of WreckSight software showing multibeam data in an interactive environment using my new visualisation methods.

Section 2

Question 7: How does WreckSight compare to other tools that you have seen?

Answer: It’s one step ahead. All other tools used for survey presents data in the same 2D pictures which is not always understandable for 3rd parties or “non insiders”.

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Question 8: With Wrecksight, is it easier to understand the wreck data?

Answer: With Wrecksight it is/was much easier to understand the “wreck”. A clear picture/image will tell you more than a thousand words! In the “California” situation the images revealed much more damage than expected and was found with previous diving inspections.

Question 9: Is it a fair comparison?

Answer: Don’t know. If time and money plays a vital role in a project WreckSight will and may not always be the best solution. Another question asked “what kind of result(s) do I want”. Wrecksight is still a costly and time consuming operation and situations may occur that all parties are happy with a basic diving inspection or limited information. Another problem arising with a highly detailed WreckSight images “do I want to show so much details”, sometimes details can be a disadvantage for a salvage company when presented to 3rd parties.

Question 10: Supplementary questions about Wrecksight

Participants are shown the following supplementary questions and answer those that they feel are relevant to their own experience:

- 10.3 How does the presentation of data in WreckSight compare to other methods that you have seen?
- 10.2 Which 3 features do you consider to be the most useful in your field of work?
- 10.3 Which 3 features are the least useful?
- 10.4 What would be the implications of using WreckSight for surveyors in the field?
- 10.9 What are the opportunities to use WreckSight for public dissemination of data?
- 10.10

Question 10.2 Which 3 features do you consider to be the most useful in your field of work?

Answer: When a highly detailed picture is necessary “for the job”, as mentioned Wrecksight is one step ahead and favourable. The 3D representation, rotate and zoom options are extremely useful in showing the wreck in an easy and simple way to 3rd parties who do not have the knowledge to understand the basic multibeam results.

Question 10.5 What are the opportunities to use WreckSight for public dissemination of data?

Answer: Environment will be more and more important in the future therefore “people” will be more and more curious what’s down there and what’s going on. If in the near future these images can be produced more easily in a fancy for common public more understandable format it will be more often used not only by salvage companies but most probably also by other parties.

Section 3

Question 11: What new features would you like to see in the future?

Answer:
• Possibility to use colors, to create a better contrast for printing or presentation purposes (background, bottom, cargo and casualty).
• Possibility to make a solid (surface model) of the wreck. To export x/y, x/z data in dxf format i.e. the 2 images used in dive route.
• The images can be used, without background in for example autocad.
• To export in above mentioned images (format ??) so they can be used in an USBL (Ultra Short Base Line) tracking system.

Question 12: Do you have any additional comments?

Answer: Not yet!
14.3 Ethics Guidelines and Forms

14.3.1 Participant Information Sheet

3D Visualisation of Historic and Environmentally Significant Shipwrecks.

My PhD investigates new methods to improve 3D visualisation of shipwrecks from multibeam sonar data. Using a number of case studies I propose three methods for improving how the data is displayed to allow more accurate representation and understanding of the wreck site.

The case study shipwrecks are potentially hazardous to the environment since they contain unexploded munitions or hazardous substances such as marine oil. The participants in the evaluation will not be subject to the hazards involved.

Multibeam sonar is used to map objects on the seabed by recording sound pulses bouncing of the target area. This data is then represented in 3D space as a series of Cartesian co-ordinates (x,y,z) known as point clouds. The standard industry methods of rendering point clouds leave room for ambiguity and misinterpretation of the target sites, due to the nature and limitations of current technologies and software applications. The three new methods that I propose may help to promote a better understanding of the condition of the sites and therefore inform the environmental management of them.

The Questionnaire

Participants in the study will be asked to complete an interactive questionnaire. This will consist of images of shipwrecks from multibeam sonar data, rendered in a number of different styles. The participant will be asked to rate them in order of preference. The results of the questionnaire will be used to evaluate the visualization methods developed through the study.

In addition, a number of expert users of multibeam sonar will be invited for interview. These interviews may be audio recorded. The recordings will be stored digitally on a secure computer at the University of Dundee until the completion of the study after which they will be deleted (by 31st December 2011).

The survey questionnaire will ask you to enter your name. This information will not be used unless you are invited for interview and also grant permission on the Participants’ Consent Form.

By participating in this survey and completing the questionnaire, you agree that you have read and understood this participant information sheet.

Contact Details:
If you need further information or have any questions about this study and your participation, please contact Chris Rowland at c.rowland@dundee.ac.uk (01382 345359)
14.3.2 Letter to Evaluation Participants

Dear Participant,

3D Visualisation of Historic and Environmentally Significant Shipwrecks

We are writing to you to invite you to take part in an evaluation procedure to explore the effectiveness of new methods to display multibeam sonar data of shipwrecks on the seabed.

Your participation will involve taking part in an interview and completing an interactive questionnaire. We estimate that the process will take about one hour of your time at a time and place of your convenience.

Could you please confirm whether you are able to take part in the evaluation and complete the consent details below:

<table>
<thead>
<tr>
<th>Name:</th>
</tr>
</thead>
<tbody>
<tr>
<td>You may use my name in the study: (please tick yes or no)</td>
</tr>
<tr>
<td>Signature:</td>
</tr>
</tbody>
</table>

Yours faithfully,

Chris Rowland

PhD candidate
Duncan of Jordanstone College of Art and Design
College of Art Science and Engineering
University of Dundee
14.3.3 Information for Research Ethics Committee

1. Project Title

PhD study: 3D Visualisation of Historic and Environmentally Significant Shipwrecks.

Chris Rowland

2. Background information

My PhD investigates new methods to improve 3D visualisation of shipwrecks from multibeam sonar data. Using a number of case studies I propose three methods for improving how the data is displayed to allow more accurate representation and understanding of the wreck site.

The case study shipwrecks are potentially hazardous to the environment since they contain unexploded munitions or hazardous substances such as marine oil. The participants in the evaluation will not be subject to the hazards involved, they will be presented with images of the shipwrecks produced using my visualisation techniques.

Multibeam sonar is used to map objects on the seabed by recording sound pulses bouncing of the target area. This data is then represented in 3D space as a series of Cartesian co-ordinates (x,y,z) known as point clouds. The standard industry methods of rendering point clouds leave room for ambiguity and misinterpretation of the target sites, due to the nature and limitations of current technologies and software applications. The three new methods that I propose may help to promote a better understanding of the condition of the sites and therefore inform the environmental management of them.

3. Aims and objectives of the study

I aim to improve the understanding of environmentally hazardous or historically significant sites of shipwrecks on the seabed through improving 3D visualisation methods of multibeam sonar survey data. The evaluation process of interviews and interactive questionnaire will gather data which compares my new methods to current standard industry methods for displaying such data.

4. Brief description of research methods and measurements

The evaluation will be in two parts: semi-structured interviews with expert users and an interactive questionnaire to be used with various groups of people.

The expert user interviews have a series of questions (see attached document) that are asked of each participant. There will be a minimum of four participants, all of whom have used multibeam data in their field of work. The interviews will be audio recorded where permission is given. Transcripts will be produced for analysis.

The interactive questionnaire contains three sections with four questions per section. The first page will describe the study and invite the participant to complete the QA. The text will explain that the QA is voluntary and that the data they supply will be anonymised before publication. The participant will type their name into a text box after agreeing to take part.
The first two sections will display shipwreck images rendered using standard industry methods which are compared to the three new methods I have developed. The participant will grade the images from 1 to 4 where 1 is the highest score and 4 is the lowest. The third section will display a still image of a detail of the shipwreck and a movie of the same detail for comparison.

The resulting data is returned by email to our secure server (in DJCAD) where it will be collated for analysis. The participating groups will use the same generic questionnaire.

5. Brief description of participants and recruitment methods

The groups participating in the interactive questionnaire will include: Design/Animation students, Researchers involved in art and design research, maritime archaeology students and members of the general public. Members of the public will access the questionnaire at public spaces such as DCA and maritime museums.

The student groups will be approached via posters and email, followed by face to face recruiting in public areas of Dundee University. Staff researchers will be invited on a one to one basis and via Hermes.

The expert users who will be interviewed have been identified already. They are leading figures from marine salvage, maritime conservation, maritime archaeology and television production. I have approached them directly through email and follow up phone conversations.

6. Arrangements for participant information, consent and debriefing

The expert user interviewees will be provided with a letter of introduction that describes the project and asks for their signature to confirm their willingness to participate.

The interactive QA groups will read an introductory explanation of the study before confirming their willingness to participate by entering their name into the first page and pressing “I agree”.

The student group will be asked to attend a group participation session at the DJCAD media lab where they will be able to access the QA on identical computers.
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