IDENTIFICATION AND LOCATION OF SUNKEN LOGS USING SIDESCAN SONAR TECHNOLOGY

By

Aravindh Srivatsav Ravichandran

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Electrical Engineering
in the Department of Electrical and Computer Engineering

Mississippi State, Mississippi

December 2005

IDENTIFICATION AND LOCATION OF SUNKEN LOGS USING SIDESCAN SONAR TECHNOLOGY

By

Aravindh Srivatsav Ravichandran

Approved:

Randolph F. Follett
Assistant Professor of Electrical and Computer Engineering
(Major Professor, Director of Thesis)

Noel Schulz
Associate Professor of Electrical and Computer Engineering
(Committee Member)

Mohsen Razzaghi
Professor of Mathematics
(Minor Professor)

Nicholas H. Younan
Professor of Electrical and Computer Engineering
(Graduate Coordinator)

Roger King
(Associate Dean for Research and Graduate Studies)

Name: Aravindh Srivatsav Ravichandran

Date of Degree: December 9, 2005

Institution: Mississippi State University

Major Field: Electrical Engineering

Major Professor: Dr. Randolph F. Follett

Title of Study: IDENTIFICATION AND LOCATION OF SUNKEN LOGS USING SIDESCAN SONAR TECHNOLOGY

Pages in Study: 48

Candidate for Degree of Master of Science

Identifying the location of sunken logs is a task of considerable interest in today's world economy. The motive of this work is to find and locate sunken cypress logs that were lost during the transit to lumber mills. Cypress logs, the types of logs used in this research have a natural resistant to rotting. High density of growth rings also helps logs not being affected significantly underwater.

The quality of these sunken logs is far superior to today's logs because of their high-density growth rings. Sidescan sonar is proposed for the work of locating the sunken logs. The images obtained by the sonar, resembling a cylinder in some aspects, can be compared with a template for pattern matching. Any image size that does not match with the acceptable size can be rejected. The objects location could be noted and the logs could be recovered.

DEDICATION

With honest humility, I dedicate this thesis work to my family, my father Mr. N. Ravichandran, my mother Mrs. Suguna Ravichandran and my sister Mrs. Yamini Davies. Without their unparalleled support, motivation and invaluable guidance, this work wouldn't have been possible. I would also like to dedicate this work to all my friends who had supported me in all the phases of my life.

ACKNOWLEDGMENTS

I proudly take this opportunity to sincerely express my gratitude towards my major professor, Dr. Randolph F. Follett, for his invaluable guidance and support throughout my thesis work and during my Masters program at Mississippi State University. There have been many occasions where I have tested his immense patience and perseverance, but with his guidance and persistent support, I have been able to overcome all adversities and challenges faced during my MS program in its entirety. I would also like to thank Dr. Noel Schulz and Dr. Mohzen Razzaghi for serving on my committee.

I would like to thank Arun Ramakrishnan, for helping me acquire thesis related materials from the library resources, and Sriram Rajan for constantly motivating me throughout my MS program. Also, I would like to thank Ashwini Mani for sharing her valuable ideas and helping me in documenting this work.

TABLE OF CONTENTS

CHAPTER Page

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

1.1 Sunken Logs : an economic perspective

Salvaging old-growth sunken logs is one of the main aspects of timber companies. Log salvaging operations occur in many states in the south, states surrounding the Great Lakes and in Canada. In the late 1800s and early 1900s, logging operations involved typically cutting the virgin timber and floating the logs down a river to the mill site. Logs were frequently tied together to form a raft, but many logs were lost during their travel downstream. Due to the narrow areas in the river or by getting caught on bank debris or logjams, many logs were separated from the raft and sank to the bottom of rivers. Many of these logs have not deteriorated over the many years they have rested on the river bottom. The reason for these logs to have a high economic value is that these timbers have very narrow growth rings, a situation that is mostly not common in today's lumber. The tightness of the growth rings and the types of trees that were cut are quite valuable on the specialty lumber market today [7].

According to the Cape Fear Riverwood Corp.'s research, approximately 18 percent of all logs that were floated downstream for processing were lost during transport [7]. Many of these timbers are still in good shape at the bottom of the rivers, preserved over time due to cool water temperatures and for those logs buried under sufficient sediment to have had anaerobic conditions.

There are various methods used to locate these logs such as diving surveys, sonar graphs, sonar surveys and substrate profiling. Concentrations of logs are usually found in bends in the rivers and where old saw mills were located.

1.2 Sunken Logs: Need for it

The demand for wood in present day-to-day life is outweighing the supply. To meet with the current demand, many timber companies have opted for the option of finding the hidden treasure: sunken logs. Also, locating these logs helps in various economic issues. It reduces deforestation to a great extent. Deforestation can in turn affect the soil erosion and the water quality. Considering all the factors, it is sure that location of the sunken logs will meet great demands in economic and monetary basis. Figure 1.1 shows the cross section cutaway showing typical positions of buried timber [7].

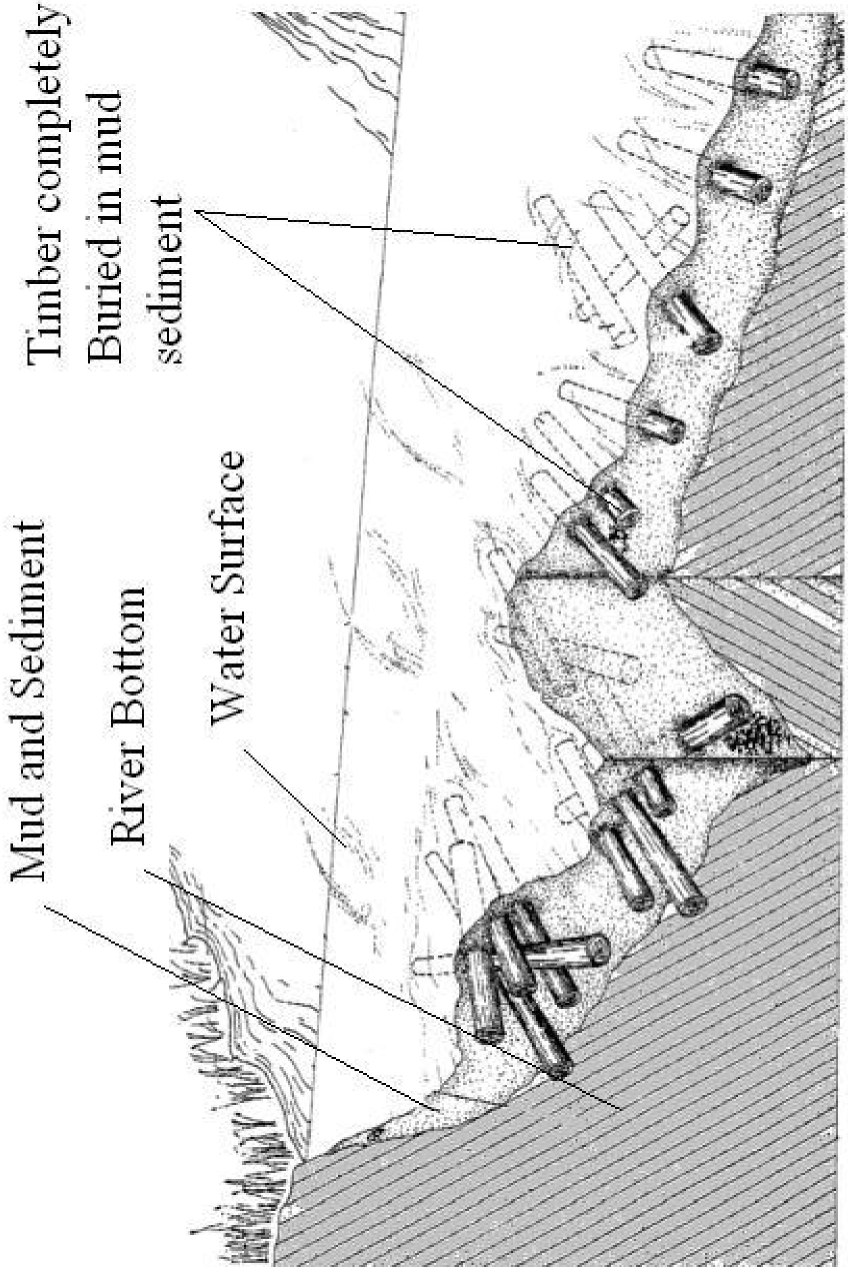

Figure 1.1 Cross-section Cutaway showing position of Buried Timber [7]

1.3 Thesis: scope and contribution

This thesis was inspired due to the large number of projects by various lumber companies to recover numerous sunken logs lying at the bottom of rivers and lakes. The aim of this project is to propose a suitable process for determining the existence of sunken cypress logs in the Mississippi river and its tributaries. These logs might have existed for many years (approximately 100 years) and have hopefully been preserved almost to perfection. These logs if recovered now will have a very high value if sold to furniture makers, architects, contractors or to instrument makers. The high value of these logs are due to the fact that the quality of the old grown wood is far superior than the present quality of wood and the fact that Cypress wood is naturally resistant to decay.

In this thesis work, a preliminary design of a sidescan sonar system for the detection of sunken logs in a riverbed is developed.

1.4 Thesis Overview

This thesis work is organized as five chapters, of which this introduction is the first. Chapter II covers some of the fundamentals of sonar, the technology used. Basic acoustic and sonar concepts are explained, including propagation of sound in various media. The implementation concepts of sonar are discussed, along with the concepts and various types of beamforming technology.

Chapter III gives further details on sidescan sonar technology, the concepts, and the advantages of using sidescan sonar. The reflectivity coefficients of various materials are discussed and tabulated along with the values for fresh water and wood, the study of which has been the objective of this research. The calculation of the distance of the target from the nadir of the sonar is discussed and also shown schematically. The study concepts of a representative candidate system, the Klein 5500 sidescan sonar is discussed along with the physical components involved and a hardware setup that could be possibly used.

Chapter IV presents the identification of the targets and the feature extraction of the same. This chapter starts by discussing the selection of the sonar and talks about the sidescan sonar imagery. This chapter also compares the multibeam focused sidescan sonar and multibeam sonar. Once the targets are identified, feature generation process helps in comparing the different templates with the extracted image. Azimuthal orientations are used in determining the optimal match in terms of correlation.

Chapter V, the final chapter, all the methodologies of the work are listed and conclusions are drawn justifying the process adopted. This chapter also discusses about the suggestions for future works.

CHAPTER II

SONAR CONCEPTS

2.1 Why SONAR?

Sound waves move more effectively in water than in air or other media. They can even travel hundreds of kilometers in the water. The ability of sound to travel such great distances in water is used in various applications such as remote sensing and target recognition. The devices that use sound in such applications fall under the category of instruments known as SONAR.

Sound waves are useful for remote sensing and target recognition in a water environment because some of the sound waves can travel for hundreds of kilometers without excessive attenuation. Other waves, like light, radio, or radar, travel only a few meters into water before losing virtually all their energy. Attenuation depends on the frequency of the sound waves. High frequency sound waves get attenuated more, while the low frequency waves can travel great distances with almost no attenuation.

2.2 Basic Acoustic and Sonar Concepts

The speed of sound in the water changes based on the conditions of the water like its pressure, salinity and temperature but is independent of the characteristics of sound itself. The physical distance between pressure fronts in a traveling sound wave is the wavelength. The number of pressure fronts that pass a stationary point in the water per unit time is the frequency of the waveform. When the local speed of the sound changes, the wavelength of the sound also changes, but its frequency remains the same. Hence the sound waves are generally described in terms of their frequency.

Figure 2.1 represents the components of the sound wave. The dark gray shade of the given traveling sound wave represents high pressure and the light shade corresponds to low pressure. The distance between the pressure fronts gives the wavelength of the sound. The size of oscillations in the pressure represents the amplitude and the amount of time between the peaks in the pressure is the inverse of the frequency called the time period [8].

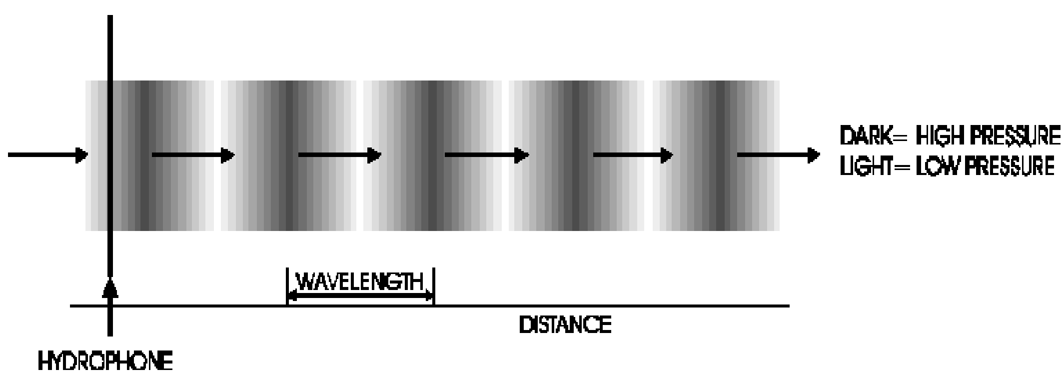

Figure 2.1 Components of Sound Wave [8]

Though acoustic energy travels well in water, a sudden change in medium interrupts them. When interrupted, some energy propagates into the new material. The amount of energy transmitted depends on various factors including the impedance of the new material, the angle of incidence, the surface roughness etc. Some amount of energy is transmitted through the medium while the rest is reflected back. The energy that is not transmitted into the material and is reflected back into the water is called an echo. The echo maintains the frequency characteristics of the sound wave. Figure 2.2 illustrates the components of echo event.

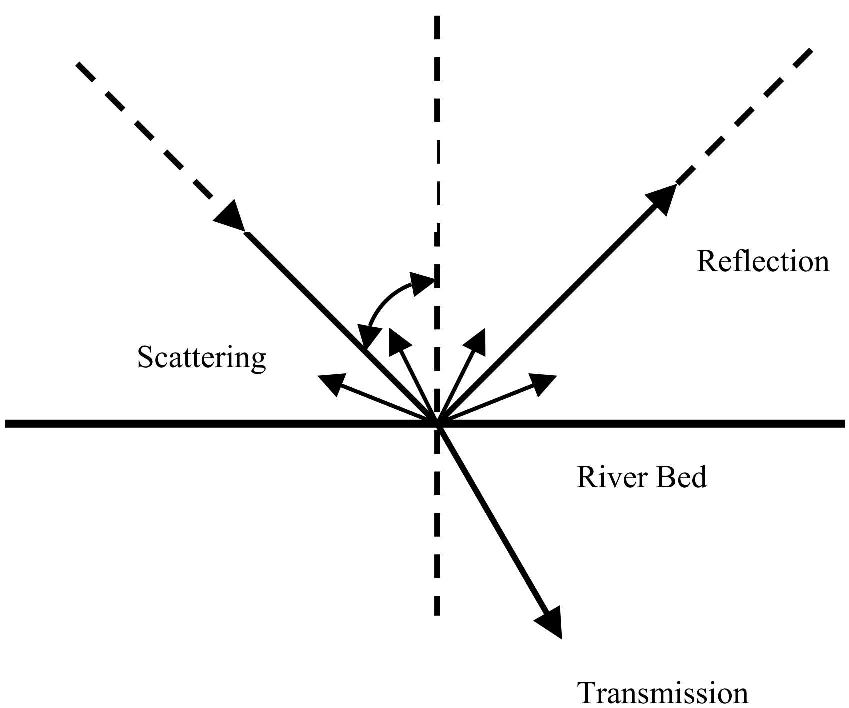

Figure 2.2 Components of Echo Event

2.3 Sonar : Principles and types

Sonar is a device for detecting and locating objects remotely in water with the help of sound. There are two basic kinds of sonar – Active and Passive.

Active sonars are the devices that are used in measuring the ocean depths and they produce sound waves of specific, controlled frequencies and listen for the echoes of these emitted sounds from remote objects in water. They can also be used in various target search scenarios.

Passive sonars are basically known as the listening devices that record the sounds emitted by objects in water. These instruments are used to detect the ships, submarines, some of the seismic events and other marine creatures - that emits sound of its own. Basically, passive sonars unlike active sonars, record the sound emitted by other objects in the water.

The most basic and most widely used echo sounding devices are single-beam depth sounders. These instruments are used to measure ocean depths at various locations separately. These recorded depths are used in making three-dimensional maps of the ocean floor by combining this depth information with their physical locations. Single-beam depth sounders consist of four basic components: a transmitter, a transducer, a receiver and a control and display system. A Ping cycle is a continuous cycle that is performed to record a series of measurements as the ship travels. Figure 2.3 shows the components of single beam depth sounder system.

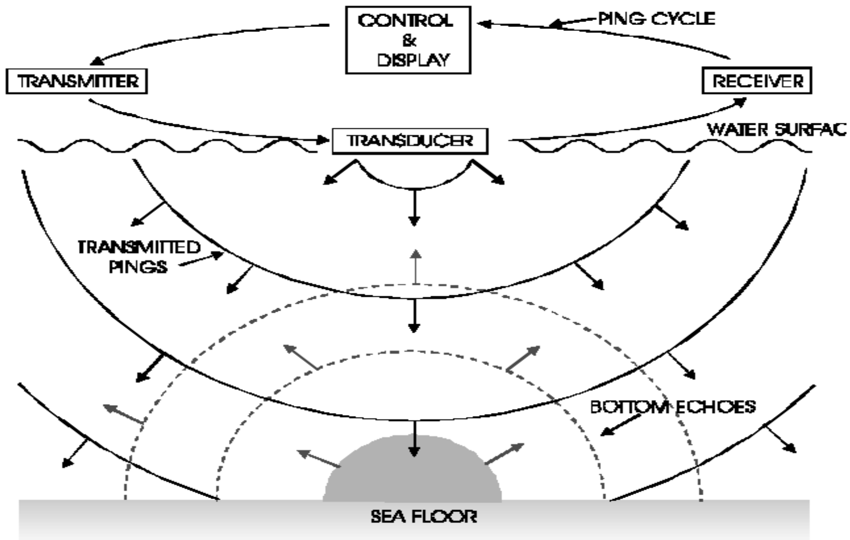

Figure 2.3 Components of Single Beam Depth Sounder System

The single beam depth sounder system has various limitations that pave the way for multibeam depth sounder system.

Multibeam sonar is an instrument that can map more than one location on the ocean floor with a single ping and with higher resolution than that of conventional echo sounders. The bottom locations are normally a strip of points arranged perpendicular to the path of the survey vessel. This area is called the *swath.* The swath of a multibeam sonar is shown in figure 2.4.

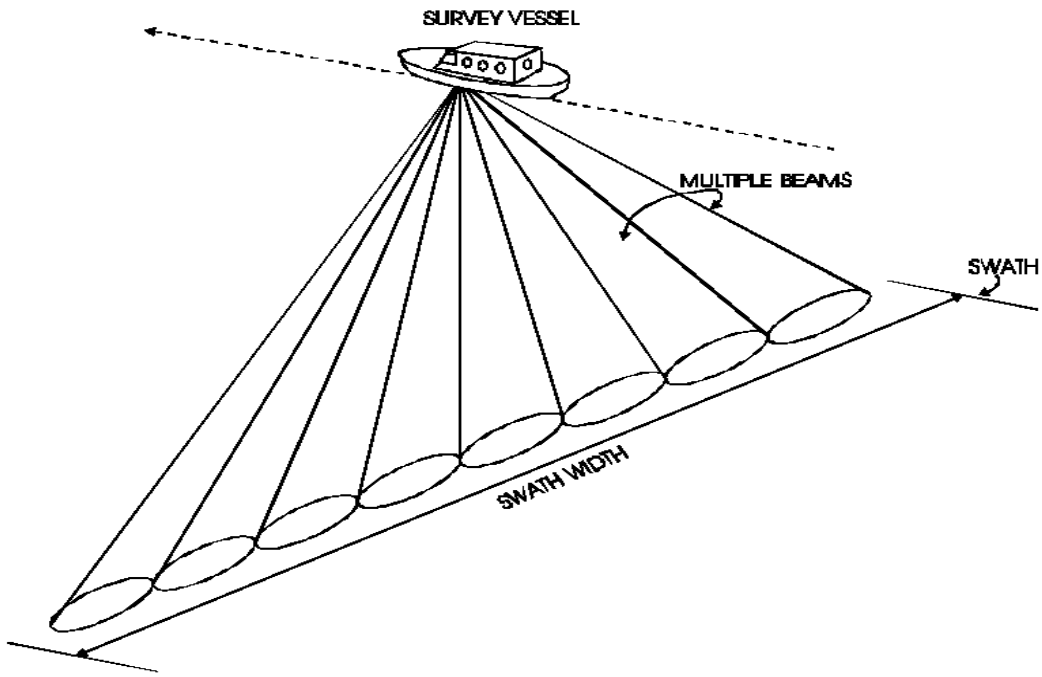

Figure 2.4 Multibeam Sonar Showing Swath

2.4 Multibeam sonar : a comparative analysis

Clearly multibeam sonars are highly advantageous. Multibeam sonars can map complete swaths of the bottom in roughly the time it takes for the echo to return from the farthest angle. This time is twice the ping cycle time taken by a single beam sounder for a 120° swath system, but such a system typically provides over 100 soundings as opposed to only one [8]. Due to the complexity of the multibeam sonar system, they are more expensive than single beam sonar. But this cost is compensated well by the advantages it has over single beam sonar. Multibeam sonar reduces the operating time by a great extent. As a result, multibeam sonars are the instrument of preference used for surveying in most mapping applications.

2.5 Propagation of sound underwater

As the speed of the sound varies with temperature (T), pressure (P) and salinity (S), there are considerable variations in sound velocity both spatially (with depth/geographically) and temporally (daily/seasonally). Horizontal variations in sound are usually small due to small gradients in T, S and P. Vertical variations in sound velocity are much larger since the vertical gradients in T, P and S are much larger.

The simplified schematic in Figure 2.5 shows idealized vertical profiles of temperature and sound velocity. The diagram can be divided into three distinct zones:

Zone1: (Closest to the surface)

There is an isothermal layer created and maintained by mixing due to wind and waves. In this layer, the sound velocity increases slowly with depth due to the increasing pressure.

Zone2: (Thermocline)

In this layer, the sound velocity decreases rapidly with depth due to the rapidly decreasing temperature. The base of the permanent thermocline normally varies greatly with latitude but is typically found at a depth of about a 1000m.

Zone3: (deepest region)

This layer is below the permanent thermocline region and the temperature change is less dramatic. As the pressure increases in this region, the velocity of sound further increases.

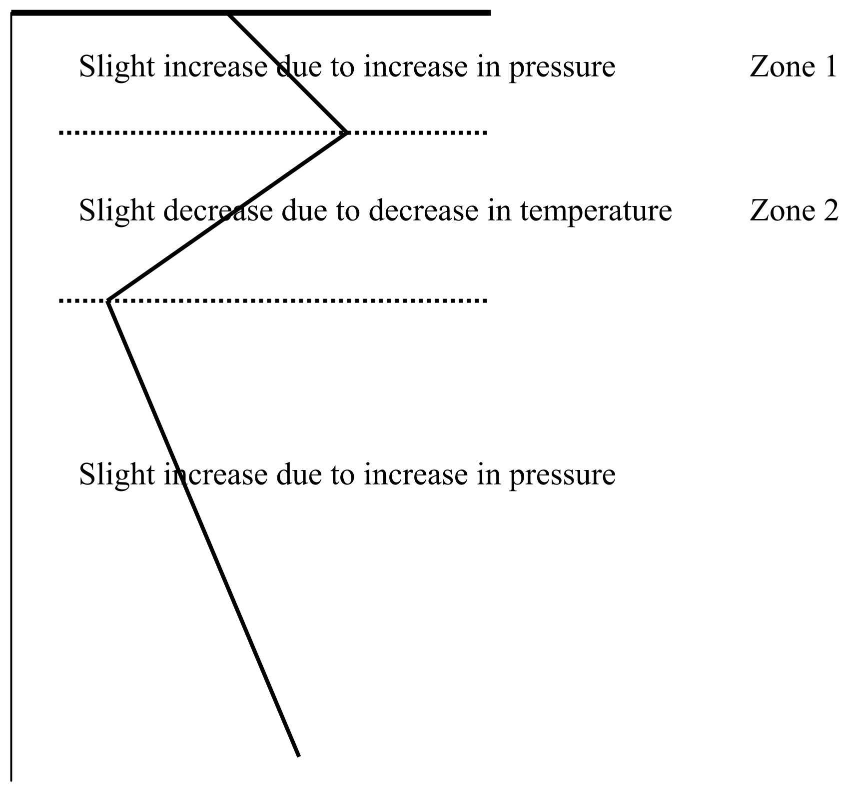

Figure 2.5 Vertical Profiles of Temperature and Sound Velocity

2.6 The Sonar Equation

The Sonar equation helps in keeping track of all the factors involved in the acoustic echoing process. This equation expressed Signal Excess (SE), the strength of the measured echo return, in terms of the quantities, Transmission Loss (TL), Backscattering Strength (BS), the Target Area (TA), and Noise Level (NL) [8]. The transmitted Source Level (SL) is also included, which is the measure of the amount of acoustic energy supplied to the water by the projector. (Projector is an instrument capable of producing a sound in water and there are various forms of them to meet specific applications). All these quantities are measured in decibels (dB):

$$SE = SL - 2TL \pm BS \pm NL \pm TA$$

Where,

SE = Signal Excess (in dB)

SL = transmitted Source Level (in dB)

TL = Transmission Loss (in dB)

BS = Backscattering Strength (in dB)

NL = Noise Level (in dB)

TA = Target Area (in dB)

The sonar equation may have additional terms and can appear in different forms. This represents that there are multiple factors involved in echo sounding and the way they relate with each other. Figure 2.6 shows the path of a ping from projector to the river floor and back to the hydrophone.

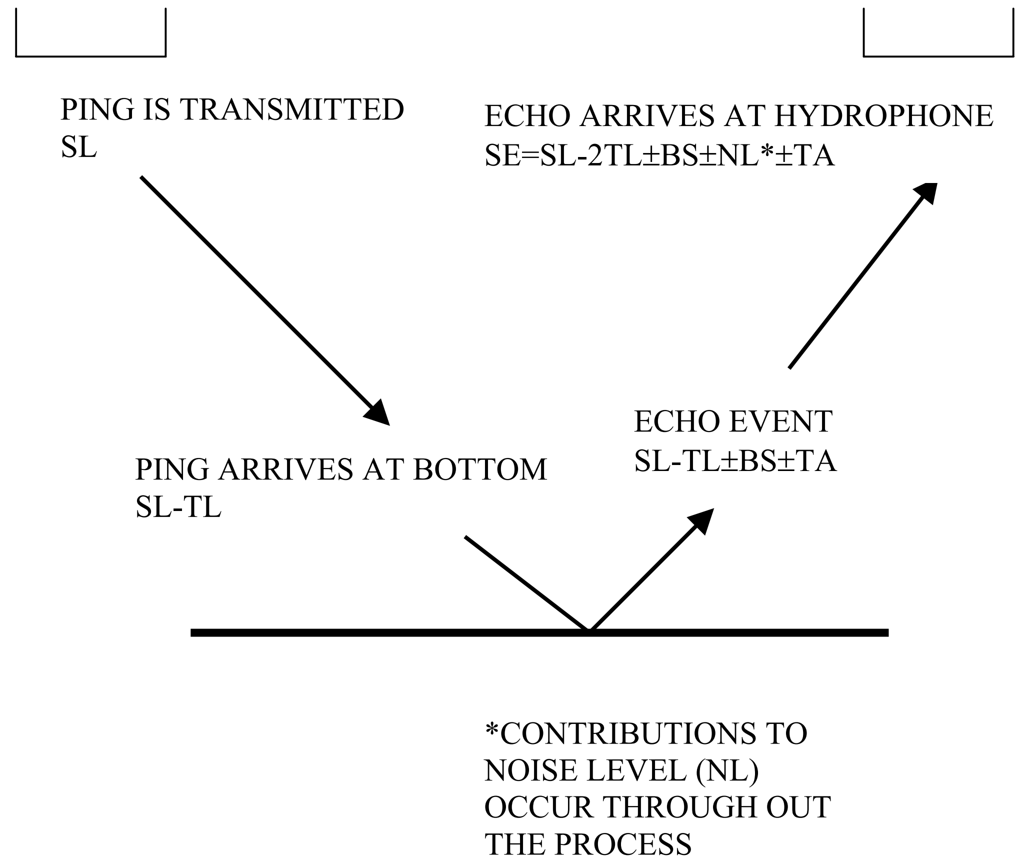

Figure 2.6 Path of a Ping

In the next chapter, details about sidescan sonar technology will be presented with consideration given to the Klein 5500 sidescan sonar, which is proposed in our work.

CHAPTER III

SIDESCAN SONAR

3.1 Sidescan sonar – what is it?

Sidescan sonars are instruments that use acoustic energy to survey the seafloor [5]. The images obtained using sidescan sonar appear similar to aerial photographs, the significant difference being that they have been taken using acoustic energy instead of light and from lower grazing angles. The other difference between them is that aerial photographs are generated using passive means whereas sidescan sonars are active. Sidescan sonars are used to provide information on the locations of objects on the seafloor by displaying backscatter levels of the seafloor [5]. The objects they are often used to find include wrecks, reefs, debris fields and sediment boundaries [5]. The position of the object, its length, breadth and also the height above the floor can also be provided by sidescan sonar.

Sidescan sonars use a horizontal line array of transducers mounted on either side of a tow body called a towfish to generate an acoustic beam which is narrow in the along-track direction and which is wide in the across track direction [5]. Figure 3.1 shows the along track characteristic generated by a sidescan sonar and Figure 3.2 shows the across track characteristics. After each ping, at a predefined delay, the transducers switch from being acoustic generators to acoustic receivers. The acoustic signal being scattered is converted into electrical energy that can be displayed by the sonar. Moving the towfish along and displaying each successive acoustic return, a swath can be generated. This swath helps in displaying the changes in seafloor acoustic backscatter. Objects and sediment boundaries can be identified by analyzing this accumulation of neighboring acoustic returns for contrasts in backscatter.

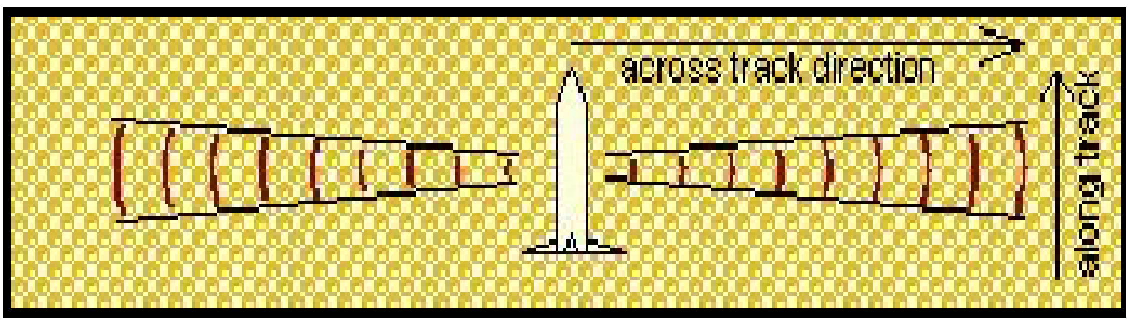

Figure 3.1 Plan View of the Acoustic Beam Generated by a Sidescan Sonar Showing its Narrow Along Track Characteristic [5]

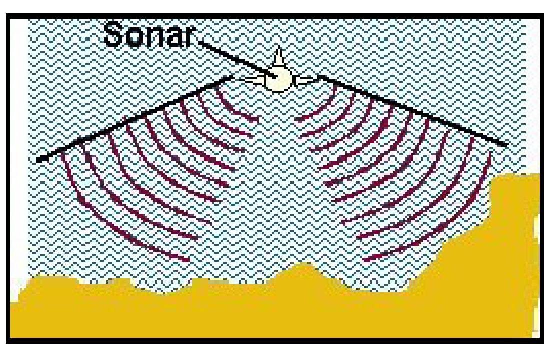

Figure 3.2 Cross-Sectional View of Side Scan Sonar Acoustic Beam showing the Across Track Direction [5]

Sidescan sonars can be towed behind a platform so that the sonar is closer to the seafloor and produces longer acoustic shadows [5]. This technique has both advantages and disadvantages. These are some of the advantages:

- It gives the highest possible detail of the bottom that may be needed for locating the objects whose dimensions approach the resolving capability of a sonar.
- Acoustic shadows are maximized and surface reflections are minimized
- The motion of the towfish is partially decoupled from the motions of the tow vessel.

Some of the disadvantages of towing sonar are as follows

- It is difficult to deploy and recover sonar in rough weathers as they require special equipment
- A Pilot should be always alert to make quick changes to avert losing the sonar on a rocky outcrop or wreck. This is because the operator cannot see what is approaching

The orientation of the object's surface with respect to the orientation of the wavefront and the acoustic impedance of the materials used in construction of the object are the characteristics of an object that determine the degree to which it reflects acoustic energy ensonifying it back to the sonars transducers. The reflection of the acoustic energy back to the sonar depends on the impedance of the acoustic target. Higher impedances produce stronger reflections. The product of the material density, ρ_m, and the speed of sound, c_m, in the material calculate the acoustic impedance. The reflection coefficient (R), expressed as percentage is another helpful quantity that indicates the amount of energy reflected back to the sonar. This is defined as the ratio of the reflected acoustic intensity to the acoustic incident intensity and may be calculated using the approximate relationship: [5]

$$R = \frac{I_R}{I_i} = \left[\frac{\rho_m c_m - \rho_w c_w}{\rho_m c_m + \rho_w c_w} \right]^2 X\,100\%$$

where:

1. I_R is the acoustic intensity of the reflected pulse
2. I_i is the acoustic intensity of the incident pulse
3. ρ_w is the density of fresh water
4. c_w is the speed of sound in fresh water.
5. $\rho_w c_w$ is the acoustic impedance of fresh water.
6. ρ_m is the material density
7. c_m is the speed of sound in the material

Table 3.1 illustrates the reflectivity coefficent and the acoustic impedance of some materials [5]:

Table 3.1

Reflectivity Coefficient and Acoustic impedance of materials

Material	**Acoustic Impedance(kg/m^2s)($x10^6$)**	**Reflection Coefficient (%)**
Air	0.000428	99.88
Fresh Water	1.48	0
Seawater	1.54	0.04
Wood (Pine)	1.57	0.0870
Wood (Oak)	2.90	10.5
Concrete	8.0	47.3
Steel	47.0	88.16

It can be seen from the table that wood has an unusually low impedance. Hence it is important that sidescan surveyors trying to locate specific objects, like logs or wrecks constructed out of wood, which have low impedance and which may be difficult to detect, need to consider the impedance of the material to be located and choose the ranges accordingly.

The horizontal distance (R_h) between an object and the sonar is calculated by taking into account the altitude of the towfish above the seafloor (H_f). The assumption is the river floor is flat from beneath the sonar (the nadir) to the object, and using the slant range to the object (R_s) [5]. Another important characteristic of objects is their height (H_t), or altitude for floating objects, above the seafloor. This can be determined by calling upon similar triangle relationships because the triangle generated by the height of the object, the length of the object's shadow and the slant range from the object's crest to shadow end (L_s) is similar to that generated using the altitude of the sonar, the slant range to the object's shadow (R_s) and the horizontal length from the nadir to the shadow, as their angles are equal [5]. By the properties of two similar triangles, the ratio of any two corresponding sides is equal, it can be stated that the ratio of the height or altitude of the object to the altitude of the sonar is equal to the ratio of the slant range from the sonar to the end of the shadow to the length of the shadow from the object.

By similar triangle properties, it can be stated as:

$$\frac{H_t}{H_f} = \frac{L_s}{R_s + L_s} \qquad (1)$$

By rearranging Equation (1), the unknown object height (H_t) can be determined

$$H_t = \frac{H_f L_s}{R_s + L_s}$$

These relationships are shown in Figure 3.3 and Figure 3.4 [5]

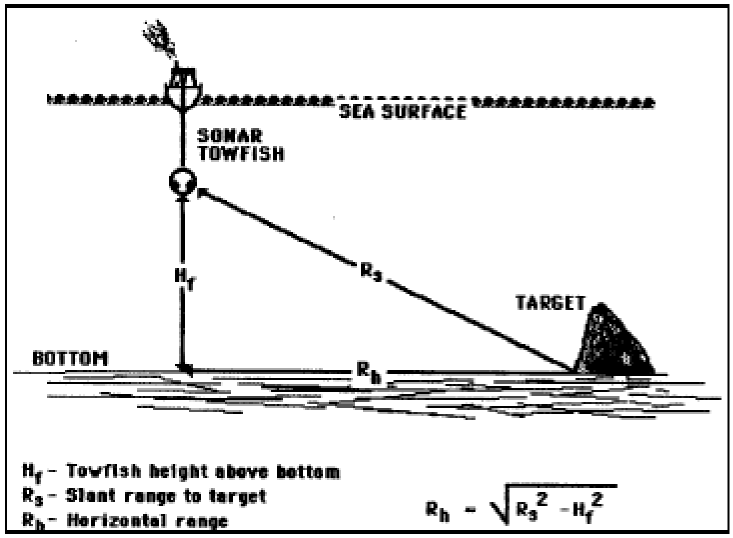

Figure 3.3 Schematic Representation Showing How the Horizontal Distance of a Target from the Nadir of the Sonar is calculated

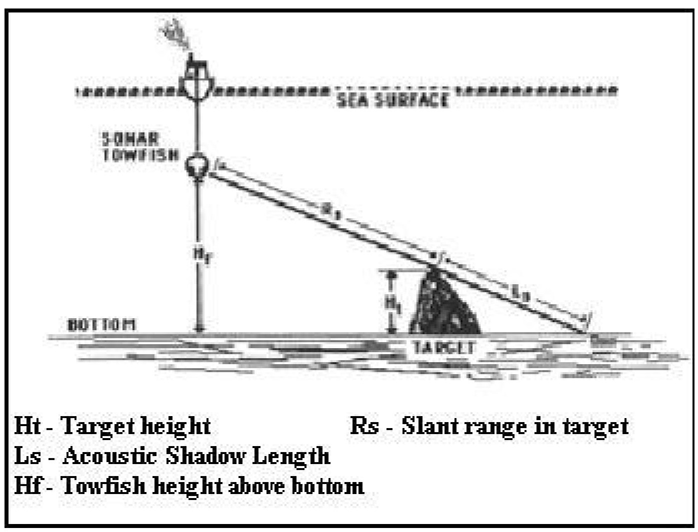

Figure 3.4 A Schematic Diagram of a Sidescan Sonar's Across Track Geometry showing how a Target's Height above the Riverbed is calculated [5]

There are various factors that should be taken into account to maintain an upper limit on the swath width to be employed by sidescan sonar while maintaining a desired resolution. Some of these factors are spherical spreading, absorption and scattering. If more than one swath is needed to survey an area by sidescan sonar, then a set of tracklines need to be constructed by an operator. Tracklines are imaginary lines that a survey vessel needs to follow in order to survey an area whose width is larger than a swath width [5]. They are normally oriented in one direction and are drawn parallel to each other. When a sonar is used to survey an area of changing bathymetry, or when the dimensions of a target needs to be checked, two sets of perpendicular tracklines are constructed instead of one. These tracklines are sometimes called as cross-lines.

The aspect ratios are non-unity for some of the objects. This means that one axis may be longer or shorter than the other. It can occur that the bearing of the ensonification is such that the sonar ensonifies the smallest possible cross-sectional area of the target. Due to the orientation of the trackline, there is a possibility that a target may be missed. To avoid this circumstance, a second set of tracklines orthogonal to the first set can be used. Then, if any targets have non-unity aspect ratios and the first set of tracklines causes the sonar to ensonify the smallest cross-sectional area, the second set will have the maximum possibility of detecting the target [5].

3.2 Klein 5500 Sidescan sonar

The Klein 5500 is multi-beam 455 kHz sidescan sonar designed for hydrographic applications [6]. These sonars operate at a tow speeds of up to 10 knots and can acquire high-resolution imagery of the riverbed or sea floor along with the bottom obstructions if any. The main benefit for high-speed sonars for both commercial and archaeological applications is its ability to survey at very high speeds without loss of bottom coverage.

For stabilizing the motion of the towfish when scanning, the Klein 5500 is equipped with three fins. The operators can easily remove these fins to reduce the possibility of snagging and losing the towfish on unforeseen objects. Under extreme load, the black yellow nose cone, where the fins are housed, separates from the towfish.

Figure 3.5 The Klein 5500 Sidescan Sonar Showing Where The Rear Yellow Nose Cone, Housing the Tail Fins, will Separate (Indicated by Red line) From the Stainless Steel Body When the Tail Fins become Snagged on Any Bottom Objects [5]

3.3 Physical Components

A dedicated computer known as the Transceiver and Processing unit (TPU) must be used in conjunction with the Klein 5500. There are various functions that a TPU has to perform. Some of them are (1) multiplexing the commands, and sending them, to the sonar, (2) controlling the number of transducers to be used in beam forming, (3) demultiplexing the data coming from the towfish, (4) parsing the sonar data through a digital signal processor, and (6) data format generation [5].

The speed of the towfish should be known to the TPU in order for it to control the number of beams to be activated in the Klein 5500. GPS navigation data or other navigation data needs to be routed into the TPU using the serial port on the back of the navigation unit. If no GPS data is received by the TPU, all the five beams on the port and starboard side of the towfish will be activated by TPU thereby oversampling the seafloor's backscatter characteristics. This will cause the data files to be over-saturated and larger than necessary.

a)

b)

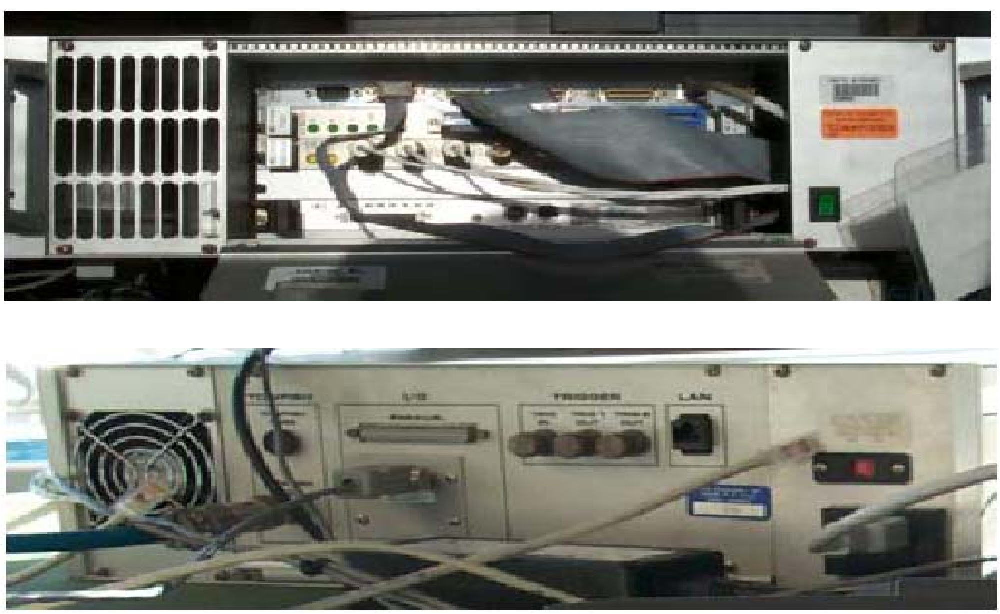

Figure 3.6 The (a) Front View and (b) Back View of the Klein 5500 TPU [5]

Normally deepwater geophysical surveys are conducted using a method known as a two-boat shoot. This technique involves two boats, the first vessel, usually with a hull mounted multibeam bathymetry system and a tow combined sidescan sonar and subbottom system behind the boat, and a second boat which records the position of the towfish from the signal of and acoustic beacon on the unit. Based on the water depths, usable data can be collected from the floor by letting out armored cable behind the tow boat to get the array close enough to the floor bed. Due to the amount of cable length extended behind the boat and due to the need to keep the array at depth, the tow vessel is limited in speed to about two knots. One of the possible drawbacks to the method of deepwater survey is positioning accuracy. Due to the influence of surface conditions and underwater currents on the tow vessel, the positioning accuracy of a deep tow system is usually only within thirty meters [6]. Since our work involves the identification of the sunken logs from a river, this disadvantage might not be relevant, due to the comparatively shallow depth of the river.

3.4 Hardware Setup

The following tabulation describes the physical components and the functionality of basic Klein 5500/Isis Sidescan System

Table 3.2

Physical Components and Functionality of Klein 550 Sidescan Sonar

Hardware	Function
1. Klein 5500 towfish	Generate and receive acoustic signal at 455 kHz
2. Fins for towfish	Stabilze towfish motion
3. Transceiver Processing Unit (TPU)	Controls towfish, send information from towfish to Isis computer
4. Armoured cable	Transmit signals between towfish and TPU
5. Isis computer	Record sonar and navigation data, controls TPU and controls data display
6. Isis dongle	Allow access to the Isis software
7. LAN/Optical cables and Hubs	Transfer data between TPU and Isis computer
8. Slip ring for winch	Allow winch to turn while data is being transferred
9. Short black cable	Connect slip ring to deck cable
10. Deck cable (blue 20m)	Connect short deck cable to TPU
11. Power cable, for 3,5,6,7 Powerboards and extension leads	Supply 240V power to equipment required

A basis physical setup is shown below. For the best positioning of the towfish, information about navigation inputs and cable-out is required.

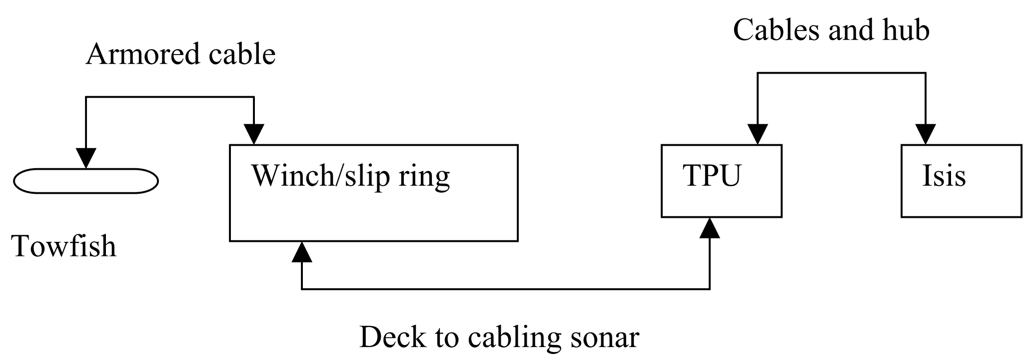

Figure 3.7 Flow Diagram Showing the Hardware Setup for the Klein 5500 sidescan sonar

The hardware of the navigation inputs and the correct software settings are not discussed in this thesis work. Interested people can refer to [6] for more exact and detailed information about these topics.

CHAPTER IV

SELECTION CRITERIA AND SONAR IMAGERY

4.1 Selection of Sonar

Selection of the sonar system forms an important part in this research work. Various factors have been considered and analyzed before selecting an appropriate instrument. In this chapter the selection criteria will be discussed. The first criterion that should be considered is whether to select a multi-transducer system or a multibeam system. Various factors were considered and a multibeam system was chosen.

In a multibeam sonar, many beams are formed simultaneously from one transmitted beam to receive the reflected energy from the subsets of the area ensonified by each transmitted pulse. The resulting pattern shows the single transmit beam intersecting the receive beams at specific areas. These areas are known as footprints. Figure 4.1 illustrates this pattern.

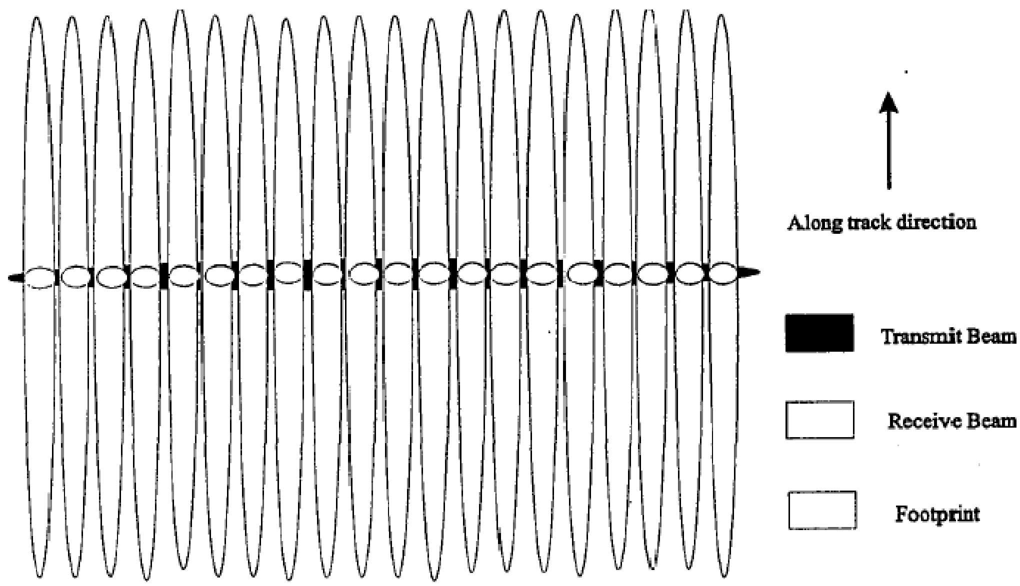

Figure 4.1 Multibeam Transmit/Receive Pattern [1]

The combination of successive transmit and receive pulses is known as a swath. The entire floor in the area of study may be mapped like a push broom cleaning a floor in a successive adjacent, inverse direction sweeps. For complete bottom coverage, successive along-track transmit pulses can be used. But to achieve this, a couple of factors must be taken into consideration when setting the speed of the survey vessel; namely the transmit beamwidth versus the transmit pulse repetition rate at specific depths. The other factor that should be considered to avoid gaps in the data is that the survey vessel must not exceed the speed at which successive transmitting pulses no longer overlap.

A multi-transducer system is the one where a ship has many transducers (simple narrow beam echosounders) mounted extending onto booms on both the sides. There are some key differences that exist between multibeam and multi-transducer systems. One of the main differences is the width of each swath. Multibeam systems cover an area up to 12 times the water depth whereas multi-transducer system's swath coverage is limited to the size of its booms in water where the depth exceeds the boom width. The other difference is that 100 percent coverage may not be obtained in shallow waters using a multi-transducer system. This is because gaps can be formed between adjacent footprints in shallow water. The final difference is that only a vertical incident energy returns is analyzed by a sweep system whereas a multibeam system looks at both vertical and oblique energy returns. Figure 4.2 shows how a multi-transducer system may cause gaps to occur between adjacent footprints in shallower waters.

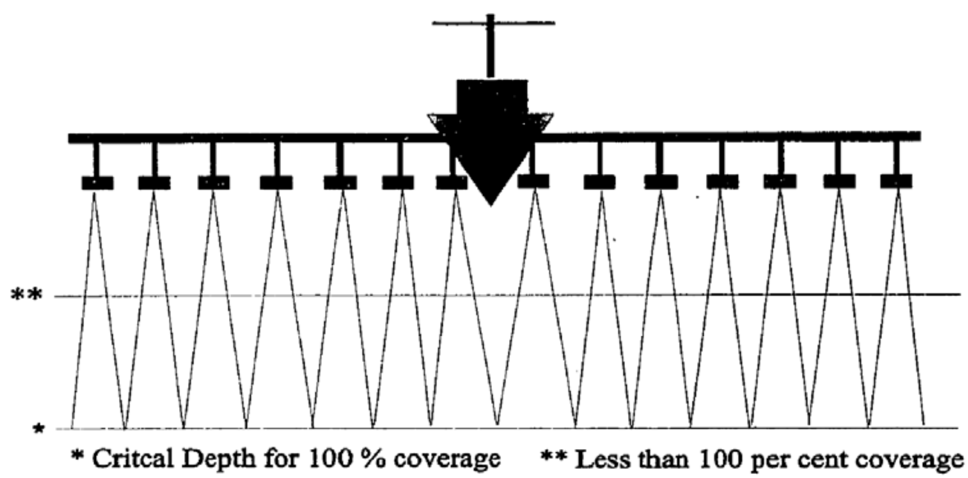

Figure 4.2 Multi-transducer configurations [1]

Beamforming is one of the most defining operations of a multibeam system. Beamforming is a term that is normally used to describe how the product of the transmit and receive beams combine to result in narrow pencil-like beams, wherever they end up being steered [1].

4.2 Multibeam focused Sidescan sonar versus Multibeam sonar

When taking into account the selection procedure for the type of sonar, the comparison between multibeam sonar and multibeam focussed side scan sonar forms an important step.

One important difference between the two is that in a side scan system, only one transducer array is used for both transmitting and receiving, but multibeam has separate receive arrays. The dualities of the side scan array results in a better resolution because of a narrower beamwidth. Traditional side scan sonar has beamwidths of about 0.75 degrees or less. This is normally less than any multibeam system available. Multibeam sonar results in decreased resolution. This is because in multibeam sonar, the receive beam is very wide and doesn't fit inside the ensonified area, resulting in decreased resolution.

Another significant difference between the two sonar in their traditional configuration (i.e. hull-mounted multibeam sonar and side scan sonar on a tow fish) is the relative positions of their transducer arrays in relation to the sea floor. The side scan array results in smaller grazing angles because of its position close to the river floor. The smaller grazing angles allow objects to cast larger shadows than compared to the multibeam systems resulting in easier identification of objects. The narrower beamwidth of side scan system results in distinct shadow cast than that of a multibeam system. Hence, due to the increased resolution and its tendency to produce larger more distinctive shadows, side scan sonar is well suited for object detection. These reasons make clear that side scan sonar could be used for detecting the sunken logs from the river. Figure 4.3 illustrates the effect of different grazing angles on side scan and multibeam system and their comparable beamwidths.

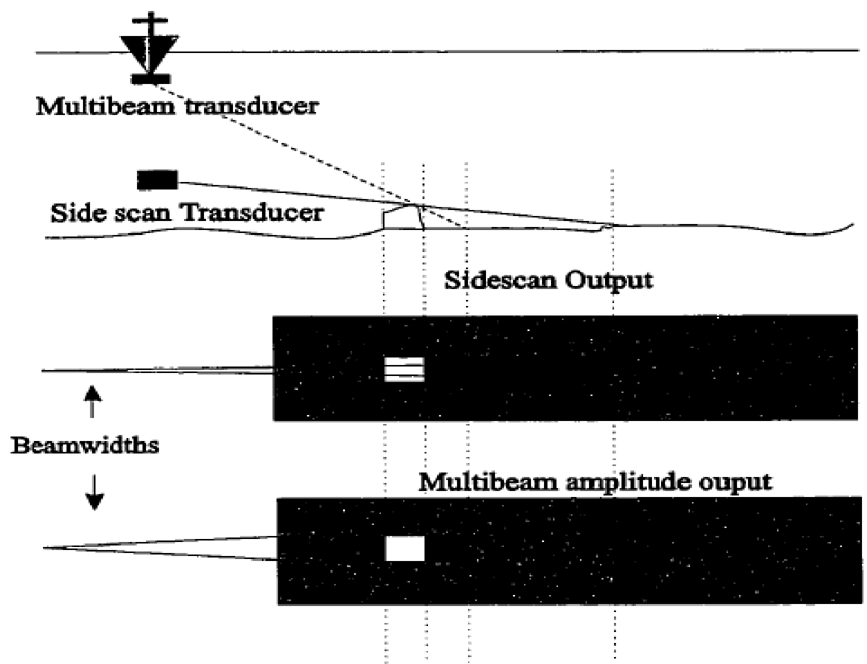

Figure 4.3 Difference in Side Scan and Multibeam Grazing Angles

However, a Multibeam system has its own set of advantages. It can be operated at a much higher speed than side scan sonar. In addition, multibeam sonar have no associated gap as found in side scan sonar. Because of these two advantages, a multibeam system leads to faster surveys with no overlap.

4.3 Sidescan Sonar Imagery

Sidescan sonar sends out regular and focused high-pitched signals on both its left and right sides when towed through the sea and listens for echoes. At regular time intervals, the intensity of the echoes between pings is recorded and translated visually as levels in a grayscale image. The echo feedback of each ping forms a row of pixels. By appropriate processing of this raw data, objects of interest can be distinguished from the seabed. Objects appear as signature bright and dark regions known as the highlight and shadow regions respectively. The high angle of incidence (the difference between the direction of acoustic wave contact and reflection) returning a high level of echo for a period are responsible for bright areas (including object highlights). The dark areas, including the object shadows, are the result of low angles of incidence and hence low level echo for a period.

It is interesting and useful to note that the shape of the highlight and the shadow and the length of the shadow all depend on the size and shape of the object. Figure 4.4 shows the geometry of sidescan sonar imagery. The relative position of the object to the sidescan sonar affects the highlight and shadow size.

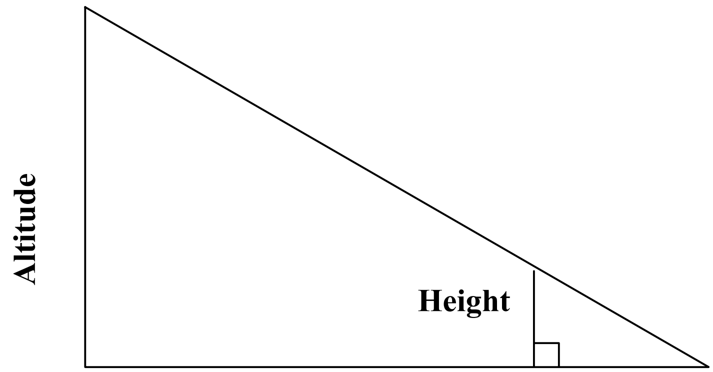

Figure 4.4 Sidescan Sonar Acquisition Geometry

The shadow lengths of bottom lying logs is affected by the height of the object, its altitude and the slant range according to the law of similar triangles [2].

$$\frac{A}{H} = \frac{SR}{SL}$$

where A is the altitude of the sonar above the riverbed, H is the height of the object, SR is the slant range, and SL is the length of the shadow cast by the object. The other factor that arises with standard sidescan sonar imagery is that there are lots of practical reasons for which an image of a target will not have exact physical dimensions. For example the shadow length might be affected if the target is partially buried or slightly tipped. This kind of problems can be solved using the approach used in [2]. The approach of the paper is to define features based on the output of template convolutions.

Sunken logs are cylindrical in shape. Templates for a cylinder of interest are precomputed using raytracing for different aspects and ranges.

One of the features of interest is the maximum correlation of these templates with the normalized version of the sonar image. In addition, a set of 10 features including convolution of edge masks, various other normalizations of the image and enlarged versions of the target template are all considered. The lower bounds are then computed on these outputs for a set of known targets and then subsequently a threshold is used based upon those bounds to know if an image is a cylinder or not. But there is a high possibility that this method raises false alarms. However, it is hoped that the images for these cases will resemble a cylinder in some aspect. This work is related to that of [3] where the concept of a deformable template is used.

Another paper related to the current work is [4] where classification was performed using the image pixel values. But it used only simulated data and restricted the images to one cross range. Principal component and linear discriminant analysis were used to reduce the number of images. From the method adopted, it is clear that the outputs from convolving the image with templates can yield valuable classification information. For instance, all the data were collected using a side scan sonar using its along track resolution. The rocks and ripples present provide clutter events. Side scan sonar is then used to perform a series of runs in various directions.

The set of cylindrical images obtained with the initial survey was used to compute various statistics for the template matching. Another set of runs along the diagonal tracks was performed for the same targets. Both these sets of data form the training set. The bounds for the feature value are computed and the other images are classified based on the threshold on these bounds. The detection threshold for the output of this filter can be set to a low level so that detection can occur [2]. Figure 4.5 shows the sidescan sonar image of one of the cylinders.

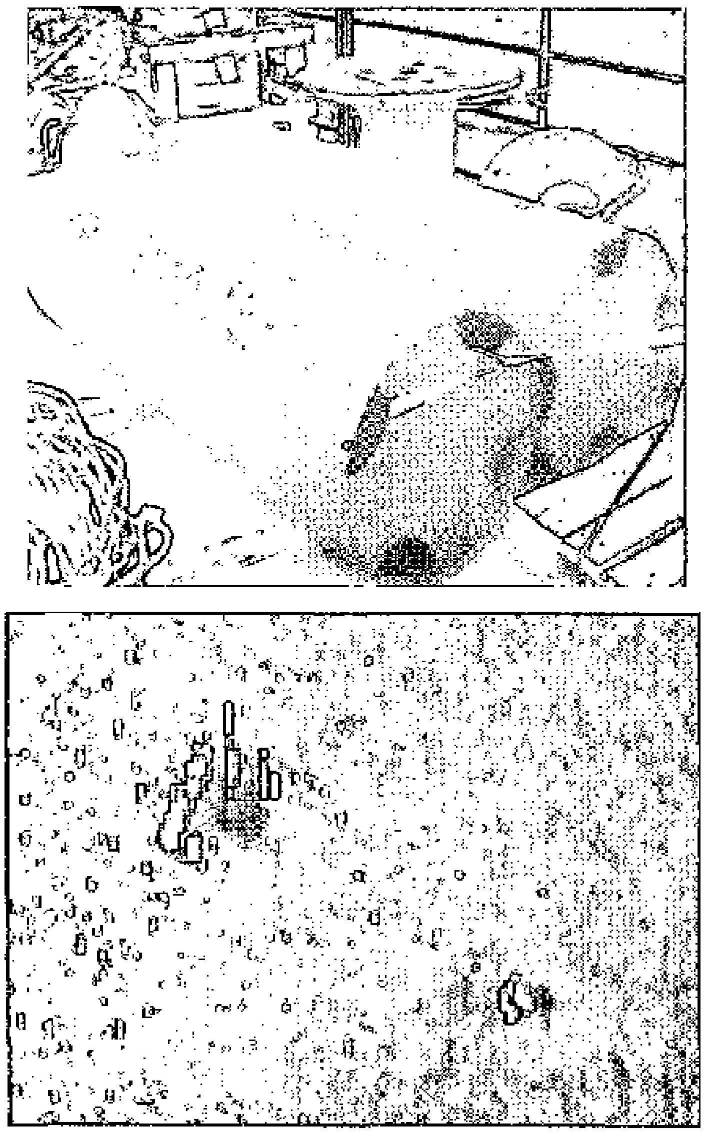

Figure 4.5 Cylinder Image and a Sidescan Sonar Image of one of the Cylinders – Note the Ringing Features [2]

4.4 Feature Extraction

The sets of data can be manually extracted from the set of swath files along with the set of associated information including the time index of the manual detections. The characteristics of the riverbed and the range of the target affect the overall backscatter levels of the sonar. In order that various feature values should not depend upon these variable conditions, it is necessary to carefully normalize the data. The procedure to normalize these data values is explained in [2]. The small image of the data values is first clipped at a factor of three times the median value and then they are scaled between 0 and 255. The mean of this data when subtracted from the image yields either positive values denoting the highlight region and negative values denoting the shadow regions. Threshol is used to denote the highlight and the shadow values. The data values are sorted and the value above a certain threshold (e.g. top 85%) as highlight and below a certain threshold (e.g. lower 20%) as shadow. This simple thresholding technique might sometimes have problems. This may not be an accurate procedure especially in areas involving poor background/shadow contrast. However in general, this approach is highly successful. The disadvantage in using this approach is that highly accurate segmentations cannot be obtained. A filter arrangement can be applied to minimize the ringing effects normally present in many of the cylinder images. Actually, one can use these “ringing” features as a very strong classification clue. It is a factor that can cause problems with image segmentation algorithms and it can also cause shadow and highlight mismatch in the template matching.

The next step in the feature extraction procedure is the computation of the matching between the different templates and the given image. Appropriate images are selected based on the range of the detection. Different azimuthal orientations are then considered to determine the optimal match in terms of the correlation. However, in few cases, if there is poor shadow structure and significant ringing, the variation of the correlation with aspect could have more than one maximum. Another form of correlation is to take the absolute value of the normalized image and the template. Figure 4.6 shows the sample templates of a cylinder at different aspects.

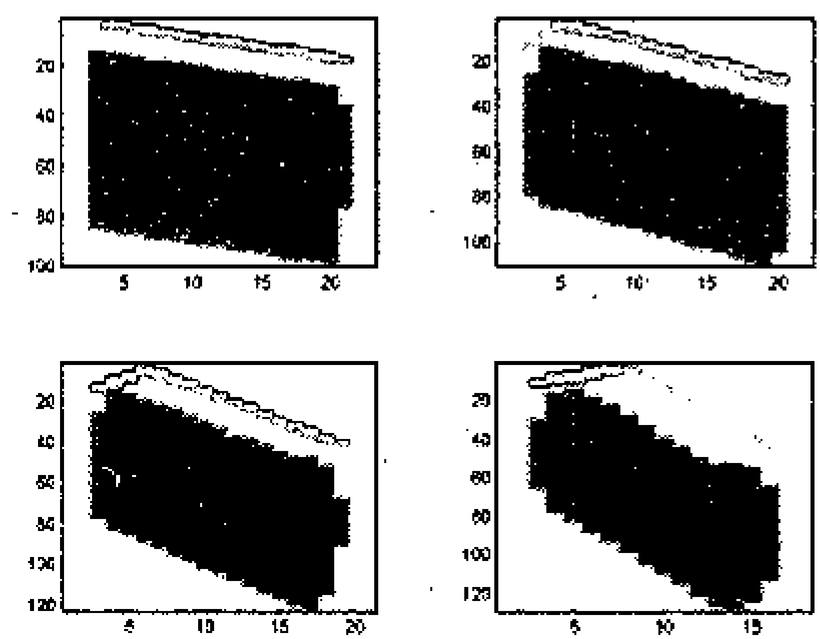

Figure 4.6 Sample Templates of the Cylinder at Different Aspect [2]

There are two important features; values of the templates and image correlation. However these two alone are not enough to distinguish the cylinders from all the clutter. In order to constrain the acceptable size of the objects, edge masks of both the images and the templates are considered. Any image size that is very different from this acceptable size can be rejected. Once the sizes of the images are matched based on this template matching procedure, the location of the object can be noted using the positioning system and a diver can be sent to recover the log.

CHAPTER V

CONCLUSION

5.1 Conclusions

In this thesis, the issue of locating a sunken log was investigated. The study was conducted on various possible techniques that could be used for this research. After thorough study, SONAR was considered because of its ability to travel great distances under water. A literature study was done on various types of SONAR and their methodologies. Multibeam sonar was suggested for the work because of its various advantages such as:

- Mapping the complete swath of the riverbed at a very high speed
- Reduced operating time

Based on investigations of multi-beam sidescan sonar, it was concluded that it is highly suitable for this research work and has numerous advantages when it is towed as summarized below.

- Several simultaneous adjacent parallel beams can be generated
- The resolution and image clarity can be varied based on the needs and at the same time almost 100% bottom coverage can be obtained.

- Acoustic shadows are maximized and surface reflections are minimized as discussed in Chapter 3 of this thesis.

Based on these advantages, it is concluded that multi-beam sidescan sonar could be used effectively in search for sunken logs. A representative candidate of a multi-beam sidescan sonar, the Klein 5500 sidescan sonar, was considered, and its characteristics and operating procedures were studied. After considering its pros and cons, it is concluded that Klein 5500 Sidescan sonar could be used effectively in this type of a mission.

Finally, the process of feature extraction was considered. In this process, manually extracted data from the swath files are compared with the different templates. A sample template of a cylinder is shown in Chapter 4, Figure 4.6.

Based on comparisons to the templates, the objects that don't fit in the size of the template can be rejected and the location of the objects that falls within the matching procedure can be noted with the help of a positioning system. Using the positions obtained through these results, logs can be recovered using various techniques. The techniques used for the recovery of the logs are beyond the scope of this research.

5.2 Suggestions for future work

In this study, process for identifying and locating the sunken logs is described. A further extension of this work could be the investigation of a suitable process to recover these logs from the riverbed. Care must be taken that this work does not have any negative impact on the environment. Some of the methods that can be adopted to recover these logs are:

- Hiring divers to run underwater saws – this procedure may be expensive and dangerous
- Uprooting the logs with a chain – this procedure may damage the river bottom and hence the aquatic ecosystem might be disrupted

It is possible that some suitable methods that are both eco-friendly and are not very hazardous can be designed and implemented.

In this work, study and focus was done mostly on sidescan sonar. Other types of sonar could be investigated for possible use in future. Even some new type of sonar could be designed in the future.

This study is mainly focused on identifying the logs in relatively shallow waters. This study could be further extended to log identification in deeper waters.

REFERENCES

[1] M.B. Brissette, “The Application of multibeam sonars in route survey”, The University of New Brunswick, 1997.

[2] J.A. Fawcett, “Computer-aided detection and classification of minelike objects using template-based features”, *Proceedings of OCEANS 2003, Dartmouth, NS, Canada, vol. 3, pp. 1395-1401, September 2003*.

[3] I.Quidu, PH. Malkasse, G.Burel, and P. Vilbe, “Mine classification based on raw sonar data: An approach combining Fourier descriptors, statistical models and genetic algorithms”, *OCEANS MTS/IEEE Conf. And Exhibition, vol. 1, pp. 285-290, 2000*.

[4] J.A. Fawcett, “Image-based classification of side-scan sonar detections” *in Proceedings of CAD/CAC 2001, Halifax, Nova Scotia, 2001*.

[5] C. Andrew, A. Young, “Setup and Troubleshooting Procedures for the Klein 5500 Sidescan sonar”, Maritime Operations Division Systems Sciences Laboratory, November 2003.

[6] D.J. Warren, Robert A. Church, “New Technology, the AUV and the potential in oilfield maritime archaeology”, C & C Technologies Inc.

[7] Submerged Log Salvage Policy Development Team, “Policy Recommendations Concerning Salvaging Submerged Logs in the Waters of Easter North Carolina”, North Carolina Department of Environment and Natural Resources, December 2000.

[8] L3 Communications SeaBeam Instruments, “Multibeam Sonar Theory of Operation”, 2000.

[9] S. Reed, Y. Petillot, J. Bell, “A Model Based Approach to Mine Detection and Classification in Sidescan Sonar”, Ocean Systems Lab, EPS School, Heriot-Watt University.

[10] C.M. Ciany and J. Huang, “Computer aided detection/Computer aided classification and data fusion algorithms for automated detection and classification of underwater mines” *Proc. MTS/IEEE Oceans Conf. And Exhibition,* 1:277-284,2000.

[11] P. Blondel and B. Murton, *HANDBOOK OF SEAFLOOR SONAR IMAGERY.* Manchester: John Wiley & Sons with Praxis Publishing, 1997.

[12] J. Tian, C. Zhang, "Automated Detection/Classification of Side-scan Sonar Imagery", *Proceedings of International Conference on Intelligent Mechatronics and Automation,* China, August 2004.

[13] P. Cox, P. Harvey, P. Rentis, K. Sivaprasad, A. Yildiz, M. Yildiz, "Sound Propagation in a Shallow Water Region Overlying A Viscoelastic Halfspace", Mechanics Research Laboratory, University of New Hampshire.

[14] R.D Stoll,., "Marine Sediment Acoustics", *Journal of the Acoustical Society of America,* vol. 77, 1789-1799, 1985

[15] N.C Mitchell, "A model for attenuation of backscatter due to sediment accumulations and its application to determine sediment thickness with GLORIA sidescan sonar", *J. Geophys. Res.,* vol. 98, 22477-22493, 1993.

[16] L3 Communications, *KLEIN SONAR SYSTEMS,* Klein Associates Inc.

APPENDIX A

DATA SHEETS

Multi-beam Sonar System 5500 Specifications [16]:

Table A.1
Specifications of Towfish

Number of beams	10 (5 per side)
Frequency	455 kHz
Pulse Length	50 to 200µsec user selectable
Resolution (along track)	20 cm to 75 m, increasing to 36 cm to 150 m max range
Resolution (across track)	Determined by selected pulse length
Operating Speed Envelope	2 to 10 knots @ 150 m Sonar Range
Sonar Digitization	12 bits per channel
Maximum Operating Range	150 m (300 cm swath)
Array length	120 cm (47.2 in)
Body length	194 cm (76.4 in)
Body Diameter	15.2 cm (6 in)
Weight in air	70 kg (155 lbs.)

Table A.2
Specifications of Tranceiver Processor Unit

Width	19 in. rack mount
Height	13.2 cm (5.2 in.)
Depth	54.6 cm (21.5 in.)
Weight	12.7 kg (28 lbs.)
Voltage	115/240 VAC 50/60 Hz
Power	120 watts
Data Output	100 Base-Tx Ethernet LAN
PC Display/Control Unit	Klein Ruggedized or Customer Supplied PC
Display Software	SonarPro Software suite
Towcable Type	Coaxial or Fiber-optic armored steel