Synthesis of acoustic images of underwater targets

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Chapter 1

Introduction

1.1 Motivation

In underwater surveys, as well as in several other fields (Automobile Industry, Home Automation, Video Surveillance, etc.), automation is becoming more and more prevalent [4]. Therefore, Autonomous Underwater Vehicles (AUVs) are becoming more widely used in tasks that were formerly performed by Remotely Operated Vehicles (ROVs). Some of the advantages of an AUV over a ROV are the fact that two or three people are enough to deploy them and once deployed they perform their task with almost no human input, they can travel at greater speeds and cover greater distances[4].

Although there have been considerable developments in data recollection technology and automated processes have been created, data analysis and treatment is still a hard and lengthy manual process. Very few algorithms have been developed to automatically analyze that data, such as the work done by Wei et al [10]. To conceive and validate those algorithms a controlled dataset of sonar data is required. Retrieving this dataset from real surveys would become expensive.

1.2 Context

This dissertation is to be developed under the Robotics and Intelligent Systems Unit of INESC-TEC.

The main objective of this work is to produce a software able to synthesize acoustic images of underwater targets that are close to real sonar images. This software is to be used to test and validate methods for automatic detection of targets, so that this task can be performed in a faster and cheaper way.

1.3 Objectives

The objectives of this project are:

- Investigate the acoustic propagation phenomena on predefined targets.
• Develop a software that is able to synthesize sonar images.
• Allow the user to define the sea floor characteristics.
• Allow the user to place a target and define its characteristics.
• Be able to define the route and speed of the AUV.
• Validate the proposed solution through data acquisition in the field.

1.4 Report Structure

This document is organized as follows:

• Chapter 2: Background and State of the Art - Describes and analyses the current solutions to the problem and provides some information about the technology used for the solution to be developed.
• Chapter 3: Proposed Solution - Details the problem at hand and the methodologies chosen to solve it.
• Chapter 4: Work Plan - Outlines the tasks to be performed throughout the project.
Chapter 2

Background and State of the Art

This section details some information about the technology behind this project and also analyzes the state of the art.

2.1 Sonar theory

The objective of this thesis builds upon the underwater Sonar (SOund Navigation And Ranging) technology. Due to that fact, background information of its basic principle of operation and different types is provided in the following subsections.

There are two main types of sonar:

- Passive sonar: only listens to sound emitted by objects in the water.
- Active sonar: produces a sound pulse and waits for the echo to return.

Only the latter is relevant to this document. Counting how long it takes for the echo to return and measuring the strength of the returned signal allows to make inferences about the distance to the target and its composition.

2.1.1 Basic Principle

![Sonar basic principle](image)

Figure 2.1: Sonar basic principle
Although it was used in acoustic location in the air, before the introduction of Radar, nowadays it is mostly used in underwater environments since sound is the only way of transmitting energy in a water environment for a considerable distance [1].

A source sends a ping (short pulse of sound) and then waits for the return signal. Knowing the local speed of sound (knowing that the speed of sound in the water is, approximately, 1500 m/s [7]) and the time it took the sound to return it is easy to determine the distance to the object:

$$\text{range} = \left(\frac{1}{2}\right) \times \text{speed of sound} \times \text{echotime}$$

A sound propagates spherically, from its source, into all directions spreading its energy. The further it goes the more energy it loses, this phenomenon is called spreading loss. The signal is also affected by some attenuation that its called absorption loss. These two losses form the transmission loss (TL). When the sound pulse hits an object some energy is transmitted into the object, varies depending on the object’s material. the amount of energy per unit are that is returned in the direction of the projector is called the backscattering strength of the object [7]. From the moment a ping is produced to the moment it is received several interferences affect the signal (boats, animals, etc.). The sum of this interferences is called noise level (NL). In order to measure the strength of the echo return, called signal excess (SE), an equation was deduced:

$$SE = SL - 2TL + BS - NL + TA$$

With SL being the signal level as it leaves the source of the ping, BS the backscattering strength and TA the target area. The target area is the area affected by the sound wave. All the values above are in decibels (dB).

### 2.1.2 Single Beam Echo Sounder

This specific type of sonar is used mainly for bathymetry and fisheries-resource surveys [2]. While it is a simple and inexpensive system, it has some problems. Having only one transducer, each ping will propagate in every direction. Because of that fact it cannot be assumed that the first echo to arrive is from the point directly beneath our transducer as shown in figure 2.2.

![Figure 2.2: Diagram showing how a Single Beam Echo Sounder works. Figure from [7]](image)
2.1 Sonar theory

Single beam echo sounders can deal with this problem, making its beam narrower, but not completely because narrowing the beam requires larger transducers, that are more expensive. Another problem with this echo sounder is that it can only produce one reading at a time, as it needs to wait for a ping to return before sending one more. This makes the process slow which in turn increases the cost of the survey.

2.1.3 MultiBeam Echo Sounder

The multibeam echo sounder solves the problems that exist in the single beam. This sonar projects several beams at the same time covering various locations, that are normally a continuous area perpendicular to the survey vessel trajectory, as seen in figure 2.3.

![Figure 2.3: MultiBeam Echo Sounder figure from [5]](image)

This technology is possible by combining several transducers in two perpendicular arrays in a Mills Cross arrangement, as done by SeaBeam Instruments [7].

2.1.4 Sidescan Sonar

Contrary to the two previous sonars this type is not used for bathymetry but for the acquisition of sea floor composition information. As was explained previously different materials have different effects in a sound pulse, the sidescan sonar takes advantage of this characteristic. The combination of bathymetry information with the sidescan sonar information provides a good image of the oceanic bottom.

This sonar has the same hardware as the multibeam sonar but with a different configuration (the arrays are positioned on the sides of the survey vessel, as shown in figure 2.4) and the data is processed in a different way.
2.2 Sonar Simulation

2.2.1 SonarSim

SonarSim is an Irish company that has developed a software that simulates an underwater sonar. This product is called PHYSicS (Portable Hydrographic Survey Simulator) [8]. It simulates Sidescan and Multibeam sonar in several types of operational scenarios.

Another product developed by SonarSim is ECHO (E-learning on the Cloud for Hydrographic Operations) [8]. This web portal gives remote access to Hydrographic survey simulation servers as well as integration of the National archive survey datasets with PHYSicS.

The information regarding this software is very limited.

2.2.2 Sonar Simulation Toolset

Developed by Robert Goddard and sponsored by the US Navy, the Sonar Simulation Toolset (SST) is a computer program that allows the simulation of an oceanic environment and the use of survey vessels in that environment and it is used to design new sonar systems, test existing sonars, predict performances, develop tactics, train operators, pla experiments and interpret measurements. This project started in 1989 and is still improved regularly. SST is only available to companies that have contracts with the United States Department of Defense. Still in [3] a vast and detailed description of the code and methods is provided.

In Goddard et al [3] a description of the following models is provided:

- The Eigenray Model - describes how sound is propagated and transformed as it travels in the ocean.

- Ocean Model - this model contains the properties of the ocean, this properties are used as inputs for the eigenray model.

- Sonar and Source Models - describes any object that can produce and/or receive sound.

- Direct Sound Propagation Models - this model inputs are all the sounds emitted by a source and the output is the portion of those signals that does not scatter on its way to the receiver.
2.2 Sonar Simulation

- Target Echo Model - the output of this model is a signal that has been received, altered and re-transmitted by a target.

This will be a very useful document as a support for the work to be developed.
Chapter 3

Project specification

The development of this project will be divided in two parts:

- Domain Logic - controls how data is created, accessed, treated, etc.

- User Interface - gives the user an intuitive and easy way to use the produced software.

3.1 Development Tools

3.1.1 MATLAB

MATLAB is a powerful software used to analyze data, develop algorithms and create models. Since it is expected of the software developed to perform a large amount of calculations and also the creation of images, MATLAB presented itself as the best way to do it [6].

3.1.2 MATLAB GUI

The creation of the graphical user interface will be designed with GUIDE (Graphical User Interface Development Environment). This is an extension of MATLAB and provides tools to create an interface in an intuitive and simple way.

3.2 Specifications

Figure 3.1 represents the connections between the several system blocs.
3.2.1 User Inputs

Before starting the scan, the user needs to define several parameters for the simulation. Such as:

- Sonar Type - Chooses between Single Beam Echo Sounder, MultiBeam Echo Sounder or Sidescan Sonar.
- Route - Defines the survey vessel route for the simulation.
- Ocean Bottom - The user is able to upload a ocean bottom datafile or generate a random one.
- Target - Allows the user to place targets, of different shapes, in the desired position on the map.
- Signal - Defines the characteristics of the ping, such as frequency and gain.

3.2.2 Sonar types

This bloc has the characteristics of the different types of sonar (Single Beam Echo Sounder, MultiBeam Echo Sounder and Sidescan Sonar) and relays that information to the next two blocs (Calculate Distance and Calculate Signal Strength).
3.2.3 Calculate Distance

Taking the information provided earlier by the user, a series of calculations are made in order to determine the distance from the survey vessel to the ocean bottom, or target. This information is then saved in an array for later usage.

3.2.4 Calculate Signal Strength

Using the Sonar equation, referenced earlier in this document, this bloc calculates the strength of the return signal and with that information makes inferences about the constitution of the object detected.

3.2.5 Synthesize Image

Using the distance and signal strength information an image is created. This is the final output of this software.

3.2.6 User Interface

This interface will provide a 3D view of the underwater environment and an intuitive menu that will allow the user to define all the specifications needed.

3.2.7 Synthesis Error

This last component will compare the synthesized image with one acquired in the field. This allows a informed evaluation of the developed algorithm.
Chapter 4

Work Plan

In this chapter is proposed an agenda for the project. This work is supposed to last 18 weeks. Some tasks were detailed but can later be changed if the need arises.

![Gantt diagram](image)

Figure 4.1: Gantt diagram

### 4.1 Task Description

- **Task 1**: Understanding completely all the phenomena involved in acoustic transmission for several predefined targets. This is the base to the whole project.

- **Task 2**: First approach to the development of the solution, to simplify in this first stage the survey platform will be static. Only the orientation of the target will be changeable.

- **Task 3**: Implementing a moving survey platform that can travel at different speeds.

- **Task 4**: Validation of the established solution by making that acquisition in a operational environment.

- **Task 5**: Writing the dissertation.
• Task 6: Creating a website that will be updated regularly. This website will have all the information regarding this project.
Bibliography


