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Automated photo-identification of cetaceans : An integrated software solution

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USE OF THESIS

AUTOMATED PHOTO-IDENTIFICATION OF CETACEANS: AN INTEGRATED SOFTWARE SOLUTION

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ABSTRACT

This study investigates current techniques used for automated photo-identification of cetaceans (i.e. dolphins and whales). The primary focus constitutes various techniques that can be applied to identify and extract dorsal fins from digital photographs. A comprehensive analysis of these techniques demonstrates the most effective software solution. To further support this analysis, four prototypes are developed to demonstrate the effectiveness of each technique in a practical environment. The analysis bases its final conclusions on test results generated from these prototype software examples. Final conclusions provide recommendations for an effective, accurate, and practical software solution. This software solution allows dorsal fins to be easily extracted from digital photographs and identified through the use of computer automated methods.

DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

(i) incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education.

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I also thank the various marine research centres, who generously contributed to my research by confirming the feasibility of this study and providing valuable statistical data.

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GLOSSARY

Cetacean: Any mammal that is a whale, dolphin or porpoise (Araabi, Kehtarnavaz, McKinney, Hillman, and Würsig, 2000, p. 1269).

Content Based Image Retrieval (CBIR): According to Traina, Figueiredo, and Traina (2005, p. 604), content-based image retrieval (CBIR), is the technique applied to quickly search large image databases, retrieving only those images whose content meets a given search predicate. The search predicate normally compares each stored image with an input image.

Digital Image Acquisition: According to Sonka, Hlavac, and Boyle (1999, p. 4), digital image acquisition is the process of capturing, constructing and storing a digital image in computer memory. A digital image is normally acquired using an image capturing hardware device, such as a digital camera or scanner.

Dorsal Ratio:

Denotes the distance between the two largest notches on the fin, divided by the distance from the lower notch to the top of the dorsal fin. The dorsal ratio is a relative measure, therefore unaffected by the size of the fin when photographed, enlarged, or even under moderate cases of parallax. (Kreho, Kehtarnavaz, Araabi, Hillman, Würsig and Weller, 1999, p. 830).

Edge Detection:

Sonka, et al. (1999, p. 77) defines edge detection as a very important local image pre-processing method. It is used to locate changes in the intensity function. Edges are the pixels where this function (brightness) changes abruptly.

Feature Extraction:

According to Sonka, et al. (1999, p. 303), feature extraction is a method employed to choose the best features from a set of available features. It must also detect the features with the highest contribution to the image recognition success.

Geometric Transformations:	Assist in eliminating the geometric distortions that occur when an image is captured. (Sonka, et al., 1999, p. 62)
Image Restoration:	"Pre-processing methods that aim to suppress degradation using knowledge about its nature are called image restoration" (Sonka, et al., 1999, p. 102).
IUCN/SSC:	Acronym for: "International Union for Conservation of Nature and Natural Resources, Species Survival Commission".
Local Pre-processing:	These are pre-processing methods that use a small neighbourhood of a pixel in an input image to produce a new brightness value in the output image. (Sonka, et al., 1999, p. 68)
Photo-Identification:	In context to this study, Araabi, et al. (2000, p. 1269) suggest that photo-identification techniques are often used for the identification of cetaceans, which normally have significant and easily recognisable markings on their dorsal fins or flukes.

Pixel Brightness Transformations:

"A brightness transformation modifies pixel brightness – the transformation depends on the properties of a pixel itself" (Sonka, et al., 1999, p. 58).

Visual Perception:

Anyone who creates or uses algorithms or devices for digital image processing should take into account the principals of human image perception. If an image is to be analysed by a human the information should be expressed using variables which are easy to perceive; these are psycho-physical parameters such as contrast, border, shape, texture, colour, etc. These concepts are all part of visual perception. (Sonka, et al., 1999, p. 33)

Image File Formats

Definitions for the image file format acronyms mentioned in this paper:

- BMP:
  "Bitmap"
- *GIF:*
  "Graphics Image Interchange"
- *JPEG:*
  "Joint Photographic Experts Group"
- *PNG:*
  "Portable Network Graphics"
- *TIFF:*
  "Tagged Image File Format"

1. INTRODUCTION

Visual recognition of individuals within cetacean study populations has significantly assisted marine biologists with research aimed towards examining the behaviour and ecology of marine mammals (Araabi, Kehtarnavaz, Hillman, & Würsig, 2001, p. 203). The IUCN/SSC Cetacean Specialist Group (1994, p. 13) also state: "...knowledge about the size, structure, and status (trends in abundance and distribution, through time) of cetacean populations is central to informed programs of conservation."

With this in mind, having the ability to uniquely identify every individual, within a study population from a photograph, can significantly assist both with research and conservation. Other reasons for adopting photo-identification procedures are the practical and legal limitations now imposed on marine researchers and conservationists. This regards human interaction and physical tagging of marine mammal wildlife. Subsequently, photo-identification techniques have proven ideal for continued study and conservation of these animals. These alternative techniques are considered ideal, because they significantly reduce (and in some cases almost completely eliminate) physical human intervention and interaction.

Until recently, the process of identifying research specimens, using photo-identification techniques, has been manually performed by the marine researcher. However, according to Hillman, et al. (1998, p. 970), as the study populations increase this process will become impractical, labour intensive, and more subject to human error. For this reason, a number of sources have suggested using a computer automated solution to solve this problem (e.g. Hillman, et al., 1998; Debure & Russel, 2001; Kreho, Kehtarnavaz, Araabi, Hillman, Würsig & Weller, 1999; Araabi, Kehtarnavaz, McKinney, Hillman, & Würsig, 2000).

This investigation will consider various methods currently applied to solve this problem. In particular, current methods adopted for image segmentation, also referred to as "extraction of objects from digital images", will be examined. Based on feedback provided by various marine researchers (see Appendix A), it is argued that current computer software implementations do not adequately meet the expectations of the researcher. Therefore new possibilities will be considered, combining existing state-of-the-art techniques to implement a more attractive software solution. Hypothetically, an acceptable software solution should meet the user's expectations of being comprehensible, automated, efficient, and accurate. It should also permit generic data entry and integrate with existing data management systems, as suggested by the feedback outlined in Appendix A.

1.1 Rationale

The ability to recognise individual marine mammal specimens efficiently and accurately has been a well established problem among researchers for some time (Kreho, et al., 1999). As maintained by Araabi, et al. (2000, p. 1269), "...the recognition of individuals is a pivotal issue in many behavioural and ecological studies of marine mammals".

Conservationists also argue the necessity of being able to uniquely identify individuals within study populations, according to the IUCN/SSC Cetacean Specialist Group (1994, p. 13). As stated by the Director for the Cetacean Research and Rescue Unit in Scotland (Appendix A):

> ...the most difficult element of an automated retrieval system is the development of a component that might be useful for matching the more difficult, subtly marked animals, particularly juveniles. I am not aware of any software that is able to reliably find individuals by dorsal shape as all appear to focus only on the position of nicks. (Dr. K. Robinson, personal communication, May 15th, 2006).

Comments given by the President of the Israeli Marine Mammal Research and Assistance Centre confirm the areas requiring investigation (Appendix A):

> ...what would be useful for us is a software package that utilises advanced analytical methods to match new photos with our own photo database. This would save us time in deciding whether we recaptured an individual or photographed a new one. We do not currently have good software that would aid in photo-ID mark-recapture analysis, so anything you may develop in that direction would be very useful for us. (Dr. D. Kerem, personal communication, May 18th, 2006).

These arguments have clearly justified the purpose of this investigation. In particular, this study has considered how current techniques can be combined and fine-tuned to provide an effective software solution meeting the expectations of marine mammal researchers and conservationists.

1.2 Research Questions

This research has been based on the hypothesis: *Effective computer vision software should accurately identify and extract the desired object from a photographic image, with little or no user intervention. This greatly enhances the efficiency of using automated photo-identification software.*

The following research question has been used to frame this study: *Is there an effective solution for implementing an intelligent and accurate software system facilitating automatic photo-identification of cetaceans, such as whales and dolphins?*

In order to answer the primary research question, five specific sub-questions must also be asked:

- *What level of software 'intelligence' is required?*
- *What level of 'accuracy' is required?*
- *Can the software solution be fully automated or only semi-automated?*
- *What is expected by the marine researcher?*
- *Can the solution be generalised to suite any photo-identification field?*

1.3 Scope

Time constraints imposed on this investigation, have affected the scope of this study. Therefore, this investigation will be limited to image segmentation and object recognition. It will also consider only those algorithms and/or methods argued as applicable for automated photo-identification of cetaceans. The main theme will constitute image segmentation and subsequently lead into the realm of object recognition. To comprehensively inform this research and conclude with substantiating arguments, the following will be used:

- Feedback gathered from e-mail communications with eleven marine research and conservation organisations, located in five different countries.

- Various established algorithms currently adopted for image segmentation and object recognition (i.e. thresholding; edge-based segmentation; contour-based shape representation and description; content-based image retrieval; and dorsal ratio matching).

- Practical software prototype implementations, to realistically demonstrate the accuracy, efficiency, requirements for user input, and overall practicality of methods discussed and compared during this investigation.

In addition, the scope of this study will be controlled by focusing specifically on the primary and secondary research questions, outlined in Section 1.2. Previous research studies, which provide possible solutions to automatically identify and match features in a digital image, will be examined. Techniques used in manual photo-identification will be compared to existing solutions that provide an alternative computer automated system.

The study will be strictly limited to secondary data collection and analysis, since any data used in this research will be derived from primary data collected by external sources, such as marine research centres. The main type of data used in this research will be digital photographs and related statistical data, provided by the participating marine research centres.

The focus will specifically target developing a solution that extracts unique features from a digital photograph, performing a combination of photo-identification techniques on those unique features. The practical ability of any emerging theoretical solutions will be demonstrated through implementing prototype software that applies these theories. However, this study will not consider the development of a full-scale software solution, encompassing database management and statistical analysis.

1.4 Organisation of Document

The following chapter provides a background overview of photo-identification and computer vision technology. This overview describes how both can assist marine researchers with uniquely identifying research specimens. A literature review, examining previous and current issues behind computer vision and automated photo-identification of cetaceans is presented in chapter three. The methodology applied to this research, including the research framework and design, are discussed in chapter four. The data analysis, including the results obtained, is discussed in chapter six. In chapter seven, the conclusions attained from this research is presented, including recommendations for future work.

2. BACKGROUND

This chapter provides a background overview of the traditional manual processes used to uniquely identify cetacean research specimens. A discussion on previous solutions, using computer vision technology to automate the traditional manual process, is then presented.

2.1 Traditional Photo-Identification Methods

Established in the previous chapter, researchers of animal behaviour and ecology generally agree it is pivotal to be able to recognise individual specimens within study populations. Artificial marking and tagging was considered to be almost essential for identifying individual specimens during the 1950s and 1960s (Würsig and Jefferson, 1990, p. 43). However, long-term wildlife research studies have proven that many vertebrates, particularly large, long-living animals, can be identified from their natural markings. Araabi, et al. (2001, p. 203) also affirm this, and develop the argument further by stating: "practical and legal obstacles to approaching and tagging the animals, accounts for a trend towards photo-identification among researchers". These impediments have encouraged researchers to identify research specimens through the use of digital photography.

Natural markings of the animal's body form the basis of photo-identification. In the case of dolphins, photo-identification would be applied to unique notch patterns, or damages, on the trailing edge of dorsal fins. Suggested by Araabi, et al. (2001, p. 203), these unique notch patterns can be visibly recognised very easily, are almost unique for every individual within a study population, and are usually permanent with very little change over time. This is also confirmed by Würsig and Jefferson (1990), Hillman, et al. (1998), and Kreho, et al. (1999). However, it has been observed that in some cases the unique notches may be progressive, which could impede the photo-identification accuracy to some extent, as concluded by Scott, Wells, Irvine, and Mate (1990) and agreed by Araabi, et al. (2001).

Information extracted from Kreho, et al. (1999, p. 830) suggests that data collection begins when an individual is sighted and a photograph of its dorsal fin is taken during research trips. Traditionally, photographs are taken using 35mm cameras with either colour slide or black and white film (Kreho, et al., 1999, p. 830). Laboratory photo-analysis then sorts the photographs, retaining only those of high quality, with a distinctive dorsal fin being the main object in the photograph. The high quality photographs are then sorted into individual fins and the outline of each fin is manually traced onto white paper. The idea behind this process is to produce uniform hand drawn replications or tracings of individual specimens, identified during research excursions.

A dorsal ratio, established by Defran, Shultz, & Weller (1990), may then be calculated for every fin that has two or more notches or damages. This theory implies that every fin can be accurately and almost uniquely identified through a mathematical calculation, so long as two or more notches or damages in the fin exist. According to Kreho, et al. (1999), the algorithm used to calculate the dorsal ratio is completely "...unaffected by the size of the fin when photographed, enlarged or even under moderate cases of parallax" (p. 830). After calculation, the dorsal ratio is recorded on the tracing of the fin. This result later facilitates matching other collections of photographs that have also been recorded and organised based on their dorsal ratio.

If two or more records are returned from the matching process, these fin tracings will be examined and compared against each other. If the tracing does not appear to match any records returned from the catalogue search, the individual will be considered a new sighting. Thus, a new record will be inserted into the catalogue.

Although extremely labour intensive this manual process proves very reliable. As indicated by Kreho, et al. (1999, p. 830), similar processes have also been used to identify other cetacean species, such as sperm and humpback whales. In order to reduce the amount of time and labour required to perform this process, not to mention human error, a computer-automated solution has been suggested. The following section discusses several key milestones attempting to provide this solution.

2.2 Combining Computer Vision with Photo-Identification

Computer vision is the science and technology behind machines that can understand what certain images represent. Most of us have at some stage heard or even used the phrase, "*A picture is worth a thousand words*", and most probably have experienced its fundamental meaning.

Our eyes provide us with an enormous amount of information about our world. Thanks to our visual capabilities, we are able to become aware of the objects and living things around us. We do this by representing their form and properties in our brains for future reference. The goal of computer vision researchers is to artificially reproduce these capabilities in machines. Stated by Groß (1994, p. 1), "given the importance of human vision, discovering the main principles of its functionality has been, and remains, one of today's greatest research challenges". For this reason, many fields have been established to research this topic. These fields range in the subjects of biology, psychology, human engineering, neuroscience, and computer science (Groß, 1994).

Due to advancement in computer technology over the last few decades, scientists have been able to develop a variety of methods to artificially process visual information. However, our biological vision capabilities are very difficult to artificially simulate. For example two images, one of a human head and one of a melon can be very similar, if taken with the same illumination. Alternatively, two images of the same head taken under completely different lighting conditions will also be very different in appearance. Yet, human vision is capable of telling the difference with very little difficulty.

To further demonstrate, a tree is composed of many intricate patterns of light and dark shades, yellow, green, and brown colours. Human vision is able to perceive all this as a single object and, at the same time, distinguish the leaves and branches that make up the entire object (tree). These examples only just begin to reveal the intricate complexities behind the human vision system, for which many of us simply take for granted. Only when we consider developing a computer vision application to simulate our own biological vision system, do we realise how complex it really is.

Currently, unlike the human vision system, computer vision technology cannot make an accurate analysis of natural images, when viewing them as a whole. This statement is backed up and discussed in detail by Sonka, Hlavac, and Boyle (1999), Duvdevani-Bar and Edelman (1999), and Hafed and Levine (2001). The underlying problem involves automatically extracting the appropriate object from the image. However, progression has been made in computer graphics, visual perception, image processing, and imaging technology, due to the technological advances in microelectronics, raster technology, and software engineering.

Computer vision experts have managed to solve many underlying problems in this field. Currently, reliable computer vision solutions are available to automatically recognise certain image objects in natural photographs, including video footage. Well researched and developed solutions include thumbprint, face, and retina recognition systems. Advanced security systems, used in areas such as military facilities and airports, employ the latest ground-breaking developments in computer vision technology. Although, this technology is rapidly advancing in some fields, it continues to remain relatively undeveloped in other less-important fields. For example, advancement of this technology is lacking considerably in the field of cetacean research and automated photo-identification, as pointed out by Kreho, et al. (1999, p. 837).

Although computer vision software systems that automate the photo-identification process of cetacean specimens exist, this field continues to demand further development. According to feedback from various marine research centres (see Appendix A), current solutions do not provide enough flexibility, efficiency and accuracy to reliably recognise every cetacean individual. Additionally, existing software solutions demand enormous user input in order to function reliably. For example, many existing solutions require the user to manually trace the outline of the dorsal fin in the photograph on the computer. This requirement considerably reduces automation, inviting inaccuracy of data and time inefficiency, due to the likelihood of human-error through requiring manual user input.

Agreeably, many computer vision systems will almost always require some degree of user input in order to operate reliably. This requirement is simply due to the fact that computers are currently unable to perceive and understand in the same way humans can. However, intelligent solutions can be employed to effectively reduce the amount of user input required to extract and recognise appropriate objects from a natural photograph. This study is therefore aimed at investigating existing computer vision solutions, particularly in the field of automated segmentation and object extraction. The following chapter provides a review of the literature, examining previous and current issues with computer vision and automated photo-identification of cetaceans.

3. REVIEW OF LITERATURE

Appropriate literature directly associated with combining computer vision technology with current photo-identification techniques is reviewed in this chapter. The literature reviewed will include sections on: photo-identification techniques, digital image acquisition, image pre-processing, segmentation, and object description and classification. Within these sections, literature on intelligent edge detection, object and feature extraction, content based image retrieval, and automated calculation of dorsal ratio, is also reviewed. Concluding sections will discuss the significance and limitations of the reviewed literature.

3.1 Digital Image Acquisition

Before processing and analysis operations are performed, a digitised image must be constructed and stored in the computer memory. This procedure is referred to as image acquisition. Sonka, et al. (1999) establish that a computer understands an image through a matrix of numbers. This makes it difficult for the computer to locate global knowledge about the image, as it must be performed using pure mathematics.

Inferred by Sonka, et al. (1999, p. 4), "...general knowledge, domain-specific knowledge, and information extracted from the image will be essential in attempting to 'understand' these arrays of numbers". Accordingly, for computer processing and analysis of an image to occur, it must first be digitally acquired and described using a matrix of numbers.

The finer concepts behind image acquisition include image digitisation, image sampling, image quantisation and colour images. Based on information given by Sonka, et al. (1999), an image is expressed as a continuous function f(x,y) of two co-ordinates in the plane. Image digitisation means that the function f(x,y) is sampled into a matrix with *M* rows and *N* columns. This illustrates that image quantitation involves assigning each continuous sample an integer value.

Consistent with Sonka, et al. (1999), after acquiring an image certain pre-processing procedures must be performed before the analysis stage. These procedures are discussed in further detail in the following section.

3.2 Image Pre-processing

Unlike humans, a computer cannot make an accurate analysis of an image when viewing it as a whole. For example, for a computer to compare two varying images of the same dolphin dorsal fin, where the background, lighting, colours and contrast on each image are different, complex problems will be encountered because it cannot easily distinguish between individual objects. This is discussed in extensive detail by Sonka, et al. (1999), Duvdevani-Bar and Edelman (1999), and Hafed and Levine (2001).

In order to develop the desired automated system, having image recognition capabilities, specialised image pre-processing routines must be appreciated and applied. Image pre-processing techniques aim to improve "...the image data that suppresses undesired distortions or enhance some image features important for further processing" (Sonka, et al., 1999, p. 57).

The most important image pre-processing routines are pixel brightness transformations, geometric transformations, local pre-processing and image restoration (Sonka, et al., 1999). These are used to enhance unique object features in the image, which is later used for a more detailed analysis of the image data. Traina, Figueiredo, & Traina (2005, p. 605) establish there are four predefined processing techniques, which can be used in image pre-processing:

1. Feature Extraction
2. Image Synthesizing

3. Unary Image Operators
4. Binary Image Operators

Although other image processing methods can be defined, according to Traina, et al. (2005), these four are considered the most common. The importance of image segmentation and how it directly relates to image pre-processing is discussed in the following section.

3.3 Segmentation

The concept of image segmentation plays a vital role in extracting unique features from an image, later used for analysis. Sonka, et al. (1999, p. 4), suggest that image segmentation is the step "...in which the computer tries to separate objects from the image background and from each other". This is consistent with a related summation by Pavlidis (1982), in that: "...segmentation identifies areas of an image that appear uniform to an observer, and subdivides the image into regions of uniform appearance" (p. 65).

Image segmentation can be divided into five main sections: thresholding, edge-based segmentation, region growing segmentation, matching, and advanced optimal border and surface detection. Sonka, et al. (1999) and Pavlidis (1982) tend to agree with this, as the same subjects are distinctly covered during their discussion on this topic. Furthermore, additional information gathered from Jaynes (1996) and Kawata, et al. (2002) strongly suggests that these particular topics are the core components behind image segmentation.

Fully automated segmentation remains an unsolved problem and manual segmentation is very tedious and time consuming (Mortensen and Barrett, 1995, p.191). In addition, "...due to the wide variety of image types and content, most current computer based segmentation techniques are slow, inaccurate, and require significant user input to initialise or control the segmentation process" (p. 191). However, as Mortensen and Barrett (1995) discuss, advancements and alternative solutions are now being developed to overcome these issues to some extent. One such solution is an intelligent, interactive, digital image segmentation technique, allowing rapid object/feature extraction from arbitrarily complex backgrounds (e.g. extracting a dolphin dorsal fin from a digital image, having background water and land scenes with very similar colours to the dorsal fin). After the required segmentation procedures are complete, analysis operations can then be performed. The following sub-sections discuss several methods of segmentation which could be applied.

3.3.1 Object Extraction Using Active Contour Modelling

The active contour model, or snake algorithm, was originally proposed by Kass, Witkin, and Terzopoulos (1998). This technique has been widely adapted as part of the image segmentation process, in computer vision and image analysis applications. In relation to Sonka, et al. (1999, p. 374), "...the active contour model, or snake, is defined as an energy-minimization spline – the snake's energy depends on its shape and location within the image". This concept essentially provides a more automated approach for detecting contours, or definitive edges, in an image. However, as Sonka, et al. (1999) affirm, this technique can not reliably find contours in images every time. Instead, this method depends on other input mechanisms, such as from the user or other automated processes, which are executed before-hand.

The gradient of an image, which contains information about edges, is used by the active contour, or snake, algorithm to find an edge in an image. In theory, this concept allows a single whole object in an image to be identified and extracted. The snake algorithm has the ability to read the gradient map as it crawls over the image. If one of the snake segments finds an edge, or mathematically greater amplitude of the gradient, that segment will remain at that position. Simultaneously, the segment that found the edge will transfer its information to neighbouring segments. This allows the neighbouring segments to also find the same edge as quickly as possible.

Active contours, or snakes, are normally used to improve a rough selection of an object in an image, which is manually performed by the user (Mortensen & Barrett, 1995, p. 191). After initialising the algorithm with a rough boundary selection of the object, the snake will iteratively adjust boundary points to achieve an accurate selection. According to Mortensen and Barrett (1995), boundary curvature and image gradient magnitude are two important factors that determine the accuracy of the snake algorithm. Unfortunately, this method on its own does not allow the user to see what the final boundary selection will look like when initial rough input selection is provided. If the resulting boundary selection is not accurate, either the process will need to be repeated or the user will need to manually adjust the boundary points.

There are two main limitations to this approach. Firstly, the initial contour (or boundary selection) needs to be quite close to the object edge. Otherwise, use of the algorithm may converge to another undesired object edge, which may be of the same or less distance. Secondly, if the desired object has an edge which is non-convex, the algorithm will have difficulty detecting the edge accurately. This is because the snake algorithm cannot easily follow the boundary of an object, where concavities exist. An adaptive technique, attempting to overcome these limitations to some extent, is discussed in the following section.

3.3.2 Intelligent Scissors

Many sources currently claim that, no fully automatic image segmentation technique is able to produce a satisfactory result for any given image. This problem is also recognised to some extent by Mortensen, Reese, and Barrett (2000), and Saitoh, Aoi, and Kaneko (2003). Although these sources make it clear that fully automated image segmentation is currently an unresolved issue, they suggest that semi-automated techniques are possible. One such technique, originally proposed by Mortensen and Barrett (1995), is called *Intelligent Scissors*.

Described by Mortensen and Barrett (1995), the *intelligent scissors* technique is an interactive tool that assists the user in extracting the desired object from a digital image. It is essentially a semi-automated intelligent tool that allows the outline of an object in a picture to be easily traced. In the case of automated dolphin recognition, this tool could be integrated to provide an alternative method for extracting the dolphin dorsal fin from a digital photograph. This would be particularly useful when a more automated approach does not produce the desired result.

Traditional methods, involving manually tracing the desired object in an image for extraction, are also inaccurate and unacceptably laborious. The *intelligent scissors* technique allows objects in digital images to be extracted fairly quickly and accurately using simple gesture motions with a pointing device (e.g. a mouse). To further explain, "...when a gestured mouse position comes in proximity to an object edge, a live-wire boundary snaps to, and wraps around the object of interest" (Mortensen and Barrett, 1995, p. 191).

As indicated by Saitoh, et al. (2003), Mortensen, et al. (2000), and Mortensen and Barrett (1995), this technique is particularly useful when the desired object to extract is surrounded by an unpredictably complex background. This is quite often the case when extracting the dolphin dorsal fin from digital photographs, as affirmed by Kreho, et al. (1999, p. 832). For example, the dorsal fin may have the same colour shades as its surrounding background (e.g. water), and the background may also consist of complex colour variations (e.g. water, land, boats, and other nearby dolphins). In these particular cases, the *intelligent scissors* technique would almost certainly be the preferred method over a more automated segmentation solution (e.g. one that uses colour gradients and tolerance levels).

Pointed out by Mortensen and Barrett (1995), *intelligent scissors* is not a new segmentation method. Contrariwise, it is regarded as a replica of the active contour, or snakes, approach with a different method of user interaction. The active contour approach requires the user to provide a rough outline around the boundary of the desired object in the image. The object will then be extracted, taking into account the processes and limitations discussed in the previous section.

The *intelligent scissors* method, on the other hand, requires the user to initially click on the starting point of the boundary around the object. The user must then move the mouse pointer around the object. In doing so, a *live-wire* (selection line) will "snap" to the boundary of the object in real-time, as the mouse moves. The method used to "snap" the *live-wire* to the boundary of the object is the active contour, or snakes, technique. This process is described in some detail by Mortensen and Barrett (1995), Saitoh, et al. (2003), and Mortensen, et al. (2000).

As pointed out in the previous section, when a sharp contour on the object boundary is found, the active contour (snakes) algorithm will have difficulty following the boundary. This is where the *intelligent scissors* technique varies somewhat from the active contour method. According to Mortensen and Barrett (1995), the user has the ability to create seed points along the boundary of the object, normally where there are sharp contour changes. The ability to create seed points makes this technique slightly more "intelligent" to the active contour method. Every time a sharp contour change is encountered, the user simply needs to click on the point where the contour change begins, and continue to move the mouse around the object boundary. This helps keep the previous selections in-tack, while quickly and accurately selecting parts of the object where sharp contours exist.

Although this technique is a very attractive solution to the image segmentation issue, it still requires fairly accurate user input. Since this method relies on the user to manually define the seed points where sharp contour changes exist, its accuracy may be flawed by inaccurate user input. Agreed by Saitoh, et al. (2003), this technique is not only prone to human error, but is also labour intensive.

An ideal solution for image object extraction should be almost fully automated with complete accuracy and efficiency whenever possible. Therefore, the traditional *intelligent scissors* technique should be used as a compromise when a more fully automated solution does not perform as desired. There exists an adaptation of the *intelligent scissors* technique, proposed by Saitoh, et al. (2003), which is fully automated and requires no user input. However, as Saitoh, et al. (2003) conclude, this technique is also flawed if the desired object is not well-focused with a well-defocused background.

Another possible solution, providing a more automated approach to image object extraction, is grey-level image segmentation. However, even though this method has many advantages, it also demonstrates various limitations, discussed next.

3.3.3 Grey-Level Segmentation

Grey-level segmentation, also called thresholding, is the process of converting between a grey-level image and a black-and-white image (Parker, 1997, p. 116). Consistent with a recent study by Şengür, Türkoğlu, and İnce (2006), thresholding is generally considered the most popular approach used for image segmentation. Similar claims are also made by Parker (1997), Sonka, et al. (1999), and Yong, Feng, and Rongchun (2004). The general concept behind thresholding is to classify the pixels in the image by their "grey-level". By doing so, an entire object can be identified, since a cluster of pixels with similar colours will normally belong to the same object.

Parker (1997) asserts that reducing the colours in the image will also assist in accurately identifying the object regions. However, as Parker (1997, p. 116-117) also considers, "...it is not generally true that a single threshold can be used to segment an image into objects and background regions". Although this is true, a single threshold is normally considered sufficient as an initial assumption. An *initial assumption*, also discussed by Parker (1997, p. 117), will roughly define and differentiate the objects from the background in an image.

The threshold value, used for the initial assumption, is calculated from an analysis of the pixel colours in the image. As stated by Parker (1997) and Yong, et al. (2004), the use of histogram significantly assists in calculating the correct threshold value. By analysing the histogram, a threshold value that best delineates the objects from the background can be calculated. As Yong, et al. (2004, p. 106) affirm, "...it is hard to design a general feature extractor. Nevertheless, histogram can be used as features for most non-texture images."

Although this technique is claimed to be used for almost every implementation of image segmentation, it can not be entirely relied on. Established by Parker (1997) and Sonka, et al. (1999), thresholding is simply used to reduce the complexity of the image, so as to simplify the recognition and classification procedures. In most cases, thresholding can not be implemented as a stand-alone method for image segmentation. Instead, it must be combined with one or more other segmentation techniques. For example, Şengür, et al. (2006) consider clustering, region growing and splitting, and multi-resolution as important segmentation methods to also investigate.

Two issues with this technique, identified by Parker (1997), include image noise and illumination effects. In addition, thresholding will most likely produce undesired results when the object has very similar colour shades to its surrounding background. These issues are more the case when natural photographs are used, as identified by Parker (1997) and Sonka, et al. (1999). For example, thresholding would almost certainly fail, if given a photograph of a dolphin dorsal fin taken on a cloudy day, with the water colour being similar to the dorsal fin.

With these limitations identified, however, it is important to realise that thresholding is not meant to be used independently. Rather, one or more other segmentation processes should be incorporated with the thresholding process, so as to produce the desired results. This is also agreed by Şengür, et al. (2006), Yong, et al. (2004), Sonka, et al. (1999), and Parker (1997).

Chapter five and six will discuss several approaches that use a combination of segmentation techniques, including thresholding, to produce the desired results. The next section explains the concept of thresholding to a higher level, by considering colour variations and gradients in natural photographs. This discussion is particularly useful, when natural colour photographs must be processed (e.g. photographs of dolphin dorsal fins).

3.3.4 Texture and Colour Based Segmentation

As discussed in previous sections, when we look at a photograph of a natural scene, we are able to easily associate regions that have similar colours with objects that we know. To illustrate, consider the scene in Figure 1. A quick glance at this scene allows us to almost instantly recognise each individual object in it, including the background. We are even able to account for variations in colour level, due to illumination effects. We can also distinguish these variations from other changes, such as overlapping objects. Indeed, the human visual system is a marvellous creation, able to overcome the most complex of problems faced by computer vision.

Figure 1: *Complexities of texture segmentation*

Retrieved November 7, 2006, from: http://swimwithdolphins.information.in.th/images/dolphin-show.jpg

A formal definition of texture does not exist, however, its "…major characteristic is the *repetition of a pattern or patterns over a region*" (Parker, 1997, p. 150). Pattern recognition techniques can generally be employed to assist with texture segmentation. However, as Parker (1997) advises, there are various random aspects to texture that must not be ignored. For example, no single algorithm can predict the size, shape, colour shades, and pattern element orientation of the texture. Instead, these must be identified through a serious of procedures and calculations.

Although texture segmentation can be automated to some extent, Parker (1997) concludes that it is unlikely any simple generic algorithm or procedure will allow accurate segmentation of textured objects in a digital image. Physical recognition of textured regions is often based entirely on perception rather than mathematical algorithms. A recent study by Sagiv, Sochen, and Zeevi (2006, p. 1633) informs "...the task of unsupervised texture segmentation has been the subject of intensive research in recent studies, attempting to discriminate between regions which have different textures". Although an effortless task for a human, Sagiv, et al. (2006) also affirm it is far from easy to perform through computer vision.

With this said, there exists certain techniques which can be employed to extract textured regions from the photograph. Both Parker (1997) and Sagiv, et al. (2006) suggest that one obvious approach is to delimit the regions by a colour or grey level tolerance. Although this approach is fairly straight forward and certainly assists in describing the problem at hand, it is not recommended. According to Sagiv, et al. (2006), a combined approach, using boundary detection with region growing algorithms, provides a general scheme for texture segmentation. Parker (1997) also considers similar strategies, particularly those involving edge-detection, surface curvature, and energy content of the image.

Heeding advice given by both Sagiv, et al. (2006) and Parker (1997), when extracting the dolphin dorsal fin from a photograph, several techniques must be employed. This is due to the problems associated with image segmentation, as outlined in the previous sections of this chapter. One or more texture segmentation techniques will certainly be required as part of the main process in extracting the desired object. Since it is assumed that most dolphin dorsal fins will resemble a greyish texture, the texture identification and extraction process should be fairly straight forward. After extracting the desired object from the photograph (in this case the dolphin dorsal fin), various image recognition techniques will need to be employed.

Although this study is focussed specifically on the image segmentation phase, a brief review of the literature required for image recognition has been documented. The following section discusses the main processes involved in matching and classifying images of dolphin dorsal fins after they have been extracted from a photograph.

3.4 Object Description & Classification

An object, also known as a shape or feature, is a unique part of the image, which has previously been identified during the segmentation stage (Sonka, et al., 1999). Currently, there is no generally accepted method for object description. Furthermore, the computer cannot possibly know what is important in the object. These summations are inferred both by Sonka, et al. (1999, p. 290-297) and Buhmann, Malik, and Perona (1999, p. 14203-14204). Previous sections of this chapter have also established other sources that substantiate these arguments.

Even so, there are general techniques and mathematical algorithms available for identifying and classifying image objects, as Sonka, et al. (1999), Parker (1997), and Pavlidis (1982) affirm. However, these sources also stress that generic techniques and/or algorithms are far from accurate when specific objects in an image must be matched and classified. In most cases, substantial reliance on initial user input is required in order for the computer to learn and obtain adequate information to automatically match and classify the image objects. However, this also presents a problem, identified by Burdea, Lin, Ribarsky, and Watson (2005), where the increasingly high expectations of the user requires minimal user input and maximum computer automation.

Maintained by Suetens, Fua, and Hanson (1992, p. 6), object description and classification involves "...finding and labelling parts of a two-dimensional (2D) image of a scene that correspond to objects in the scene". Further stated by Suetens, et al. (1992, p. 6), models, or general descriptions of each object, must first be established in order to perform related recognition tasks. By defining an object model, a description of its shape, texture, and contextual knowledge must be included. These descriptions will normally be mathematically formulated for this process. This further justifies the argument to ensure the image segmentation phase is well implemented and reliable, before continuing to the final object description and classification phase.

After the required object description and classification methods have been applied, enough descriptive information about the image should be available to perform one or more comparison routines. These comparison routines are the final phase and normally used to compare the similarities of specific objects in two or more images. The following sections discuss three important classification and comparison techniques required to reliably find a given dolphin dorsal fin in a database. These techniques are considered important based on results given by previous investigations (Araabi, et al., 2001; Debure and Russel, 2001; Hillman, et al., 2002; Kreho, et al., 1999; Würsig and Jefferson, 1990; Arrabi, et al., 2000; and Hillman, et al., 1998).

3.4.1 Content Based Image Retrieval

As discussed earlier, comparing images is a complicated process, provoked mainly by the lack of a specific description on how to carry out the comparison. Complications also arise due to images consisting of unique aspects, which can each be individually or collectively considered during the comparison process (Traina, Figueiredo, and Traina, 2005, p. 604). This normally leads to several comparison criteria. For example, when comparing two images of a dorsal fin, we may be interested in colour similarity, dorsal fin shape, and any unique damages or identifying marks on the fin. These criteria may all be taken into account to produce reliable comparison results.

The goal of Content-Based Image Retrieval (CBIR) is to search an image database and retrieve only those images which content meets the search criterion. The search criterion is normally a comparison of each image in the database to a given image, which is the criterion. Stated by McDonald and Tait (2003, p. 80), "...CBIR is an approach that bypasses the need for human indexers by automatically extracting index data from images in the form of low-level visual content such as colour, shape or texture". Another point to take into consideration is that CBIR operates on all unique parts of the image, including the background (Sonka, et al., 1999; Traina, et al., 2005; McDonald and Tait, 2003).

Since CBIR is a very fast image recognition technique, it could be employed as a first process in finding an image. As affirmed by McDonald and Tait (2003), current CBIR techniques do not require significant user input and are extremely efficient. Therefore, it can be used as an initial classifier to reduce the amount of images required to compare during a more robust image comparison process. For example, to find an image of a dolphin dorsal fin, a CBIR routine can be performed on the existing database. This operation would return all images with similarities to the dorsal fin being looked for. It may even return the correct image with the highest similarity probability. A more robust comparison routine may then be performed on the results returned from the CBIR operation.

As affirmed through the recommendations given by other investigations (Sonka, et al., 1999; Traina, et al., 2005; McDonald and Tait, 2003), the CBIR procedure is very fast and accurate. However, it is also important to note that in order for this process to be effective, the images need to consist only of the object to be compared (e.g. dorsal fin). This is where the image segmentation phase becomes noticeably important. To further explain this concept, a CBIR operation simply creates two classifications. The first classification will be a list of images with a high similarity probability to the image being looked for. The second classification will consist of all other images that do not have a high enough similarity probability ranking, and can therefore be ignored. This routine quickly and effectively reduces the number of images required to compare during a more robust image comparison operation.

Content Based Image Retrieval (CBIR) is considered a vital component in computer vision technology to date, established by Sonka, et al. (1999), Traina, et al. (2005), and McDonald and Tait (2003). However, in most cases, it can not be exclusively relied on. Instead, CBIR must operate in conjunction with other more robust image comparison techniques, specifically designed for the comparison being performed. The next section discusses one of these techniques, particularly useful in comparing dolphin dorsal fins.

3.4.2 Automated Identification of Unique Object Features

Extracting the appropriate features of an image is essential for the suitable design of any pattern classifier. However, developing a general procedure to effectively extract unique features from any given image remains an extremely complex and challenging problem. Consistent with Buhmann, et al. (1999, p. 14204), the greatest challenge of computer vision, "...lies in constructing a unified framework for modelling image content with appropriate semantic abstraction levels". Another issue is again directed at image segmentation, as pointed out by Yeh, Grauman, Tollmar, and Darrell (2005). Further suggested by Yeh, et al. (2005, p. 2025), to automatically discern the object features is a very challenging task, when the image consists of other objects or background formations. However, if the image segmentation phase has successfully extracted the appropriate object from the image, then automated identification of the object features is certainly possible.

In the case of dolphin dorsal fin recognition, several features will need to be automatically identified. Based on the results of investigations from Araabi, et al. (2000), Kreho, et al. (1999), and Hillman, et al. (2002), the most important features required for extraction include the fin shape, colour, texture, and damages. It is generally considered that the damages in the fin are the most important unique features to identify.

In proportion with Hillman, et al. (2002), an automated feature identification method should consist of an algorithm to describe the notch (damage) patterns in the fin. Hillman, et al. (2002) suggests that automated feature extraction is most effective on fins with reasonable notch patterns. Fins that have a strongly curved shape, with relatively small notches, will not perform as well with the automated system. However, if the feature extraction process considers the fin shape, colour and texture, such as in CBIR, the comparison process should still return a reliable result. These arguments are also confirmed and justified by Araabi, et al. (2000) and Kreho, et al. (1999). Damages in the dorsal fin are normally calculated using an algorithm called the Dorsal Ratio. This algorithm has been employed as one of the most common techniques for uniquely identifying dolphin specimens for some time (Kreho, et al., 1999). The following section discusses the application of this technique in an automated computer system.

3.4.3 Automated Calculation of Dorsal Ratio

As discussed in chapter two, marine researchers use a mathematical algorithm, called the "Dorsal Ratio", to uniquely identify each dolphin in a study population. Consistent with Kreho, et al. (1999), the dorsal ratio is calculated based on the relative distance between two of the largest notches (damages) and the tip of the dorsal fin. However, as agreed by various sources, such as Kreho, et al. (1999), Araabi, et al. (2000), and Hillman, et al. (2002), manually calculating this ratio is exceptionally time consuming, laborious, and user dependent.

Maintained by Kreho, et al. (1999), generally, the selection of reliable features in an image object is a challenging task. Kreho, et al. (1999, p. 835) further states "...the most desirable features are the ones invariant to translation, size, and rotation variations". These arguments are also substantiated by Araabi, et al. (2000) and Hillman, et al. (2002). However, since dolphins can be reliably identified based simply on their fin's dorsal ratio, feature extraction becomes slightly less complicated. This is because the dorsal ratio is dimensionless, insensitive to translation, size and in-plane rotation (Kreho, et al., 1999, p. 835). According to Arrabi, et al. (2000) and Kreho, et al. (1999), the dorsal ratio is defined as... $DR = \dfrac{D(B,C)}{D(A,C)}$

Also indicated by Kreho, et al. (1999, p. 853), the function $D(P_1, P_2)$ is the Euclidean distance between points P_1 and P_2 in a Cartesian plane. The variable A is the tip of the dorsal fin, and variables B and C are the deepest points of the two most prominent notches. Because the curvature of the fin's edge provides a unique representation, points *A*, *B*, and *C* are defined as local maximum and minima of the curvature function. By finding two of the strongest minima (notches) and the strongest maximum (fin tip), the dorsal ratio can be automatically calculated. This is illustrated in Figure 2 below:

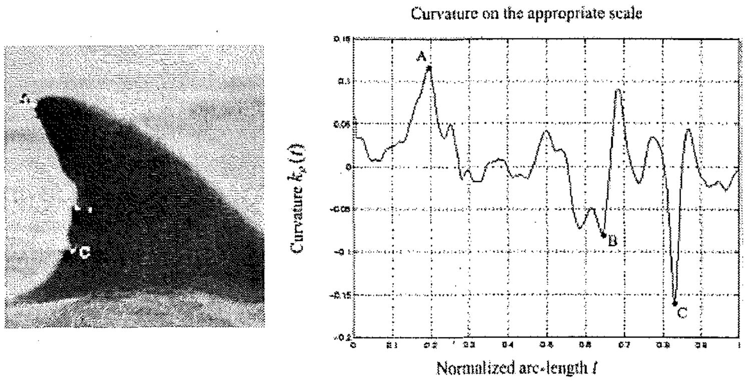

FIGURE 8. Characteristic points A, B, and C in the image and curvature signature. A is tip of the fin, and B and C are the deepest points of two most prominent notches. Curvature function is given at $p=p_{app}$.

Figure 2: *Calculating the dorsal ratio*

Extracted from Kreho, et al. (1999, p. 836)

Agreed by Araabi, et al. (2000), Hillman, et al. (2002), and Kreho, et al. (1999), a computer automated approach for calculating the dorsal ratio is highly preferred over the traditional manual approach. Not only is it more time consuming and less laborious, it also significantly reduces human error. As Kreho, et al. (1999) suggests, "...the computer approach is more consistent in the sense that it does not depend on human biases" (p. 386). Therefore, conclusions suggest that it is essential for the dorsal ratio to be accurately calculated through an automated process. Section 3.5 will discuss the significance of the literature so far reviewed.

3.5 Significance of Literature

Established in this literature review, image segmentation is the key factor in a successful and reliable computer vision system. A review of the literature, combining computer vision technology with current cetacean photo-identification techniques, has resulted in a justifiable need to further develop and enhance the image segmentation process.

Throughout the review of this literature, limiting factors have been identified, pointing directly back to the issues involved with automated image segmentation. This presents a substantiated argument that focuses this study primarily on issues surrounding automated image segmentation. Further development can focus on the feature extraction and image comparison processes. As identified during this literature review, these key processes cannot successfully produce reliable results without first accurately extracting a desired object from the image. Therefore, concepts and theoretical methods identified and discussed during this review will be employed to provide the basis for this study.

4. METHODOLOGY

Methodology employed for this study is presented in this chapter. A discussion on the chosen methodology will cover: applied research framework, implemented research design, developed strategies for data collection and analysis, and method used to support and maintain the validity of the research. A brief overview of selected data for this research is also provided, followed by a more in-depth discussion on the data analysis in chapter five.

4.1 Research Framework

Qualitative and *quantitative* frameworks have been applied in this research using a *mixed method* approach. The quantitative framework has been applied to answer the research questions pertaining to the "...relationships among measured variables with the purpose of explaining, predicting and controlling phenomena" (Leedy & Ormrod, 2001, p. 101). In contrast, Leedy and Ormrod (2001) suggest that qualitative framework "...is typically used to answer questions about the complex nature of phenomena, often with the purpose of describing and understanding the phenomena from the participants' point of view" (p. 101). According Punch (1998, p. 240), the main differences between the two approaches "...lie in the nature of their data, and in methods for collecting and analysing data". However, Punch (1998, p. 240) emphasises that caution must be taken to ensure these differences "...do not obscure the similarities in logic, which makes combining the approaches possible".

By combining both the qualitative and quantitative approaches, Punch (1998, p. 246) suggests that the researcher will be able to capitalise on the strengths of both approaches, and the weaknesses of each approach will also be compensated for. This study has therefore adopted the *mixed method* technique, following the approach defined by Punch (1998, p. 247) where "quantitative research facilitates qualitative research". Following from this, the applied research design will be discussed.

4.2 Research Design

This research has been sequentially conducted, with qualitative case studies and other associated data collection and analysis techniques being applied first. The qualitative approach was employed to conduct a more thorough analysis of each identified method for image segmentation. The quantitative approach was then used to compare the various identified methods. Comparison criteria include the level of automation, accuracy and efficiency of each method. The criterion for each method was benchmarked to provide a more exact comparison. The results obtained were combined to identify the most effective solution.

In addition, the study also applied secondary data analysis techniques, where the collected data was reanalysed from "...previously collected and analysed data" (Punch, 1998, p. 107). Although primary data is presented during the collection of survey results from various marine research centres, this research mainly constitutes secondary data analysis. This has simplified the data collection process, eliminating or reducing various limitations such as the research time, ethics, and resource bounds. If primary data collection and analysis techniques were mainly employed, the study would have been significantly more extensive, requiring more time and resources. However, for this particular research study, secondary data collection and analysis techniques are regarded as adequate. An overview of the design strategy is illustrated in Figure 3:

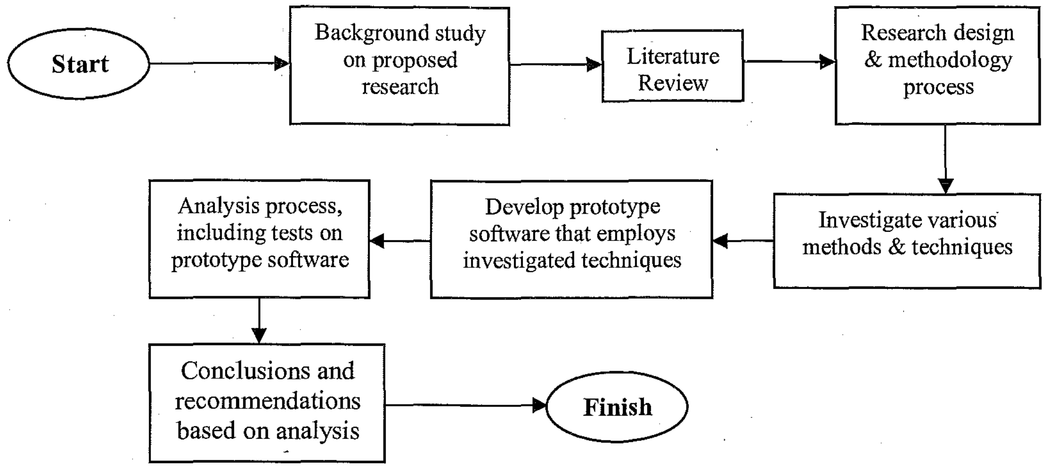

Figure 3: *Design strategy for this research*

Limited secondary data has been collected from external sources (i.e. marine research centres) for the purpose of this study. This data consists of specific feedback provided by various marine research centres, including digital photographs of dolphin dorsal fins. The techniques examined during this study are analysed through the development of prototype software. The prototype software was used to test the various techniques discussed, providing realistic data analysis results and allowing final conclusions to be drawn. The next section discusses how the data was collected in more detail.

4.3 Data Collection

The data collection process has followed the plan suggested by Leedy and Ormrod (2001, p. 111), to ensure enough data from the required sources are collected in order to adequately satisfy the research questions. Suggested by Leedy and Ormrod (2001, p. 111), "...the researcher must also make decisions about how to acquire and interpret the data necessary for resolving the overall research problem." As discussed in the previous section, this study has only collected secondary data. Although Leedy and Ormrod (2001) specify that primary data is the most reliable source for a research study, secondary data must sometimes be used as a compromise. Secondary data is not collected from the source itself, but rather from the primary data. Indicated by Punch (1998, p. 107), secondary data collection is often preferred, as it costs less to collect, is more easily accessible, is of higher quality, and takes less time to collect.

Based on this information regarding data collection, this research has collected data from the following list of primary sources:

- **Review of the Literature**

The literature review has allowed conclusions to be drawn outlining algorithms that are currently available. These algorithms must also prove appropriate for this study and demonstrate applicability. From the review of available methods and/or algorithms, prototype software can then be implemented to test these theories. From the results of these tests, conclusions for this study's research questions can be drawn.

- **Personal Interviews and Surveys**

To assess the feasibility of this research study, including the topics it should cover, personal interviews and surveys have been conducted. Personal communication with various marine researchers has assisted to identify the particular areas that require attention, specifically regarding automated photo identification of cetacean research specimens. In addition, various marine research centres have also participated in a survey, confirming the areas that need further development. The following outline provides a general overview of the type of questions asked during the interviews and survey.

  - Most frequently used software systems by marine researchers
  - Properties of collected and electronically stored digital images
  - Common fields/attributes associated with each digital image
  - Required accuracy of image identification and matching
  - Required efficiency of image identification and matching
  - Requirement to integrate into larger DBMS system
  - Ease-of-use and user-friendliness required of software

- Amount of manual data entry expected

- **Tests Performed on Prototype of Proposed Software**

Development of prototype software has assisted in determining the level of automation, accuracy and efficiency of each method discussed in the literature review. These methods relate to computer vision and are found to be particularly useful in the development of an automated photo-identification system for cetacean research. In order to draw reliable conclusions, various tests must be performed on the prototype software. The following list outlines the general criteria for testing these prototypes:

- Efficiency
- Accuracy
- Ease-of-use
- Amount of manual user input required or permitted

Due to the range and nature of required data, the qualitative and quantitative data collection strategies discussed by Punch (1998) have been applied, regarding the discussion in section 4.1. Following this plan, and related strategies, it has significantly assisted in reducing the risk of using low quality data.

4.4 Data Analysis

Data analysis has been conducted by various means. This research has followed the data analysis spiral model adapted from Leedy and Ormrod (2001, p. 161), see Figure 4. This model has been specifically employed for the analysis of qualitative data.

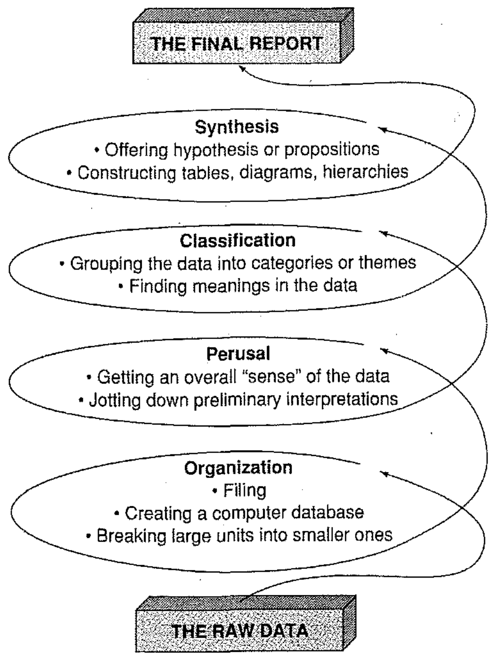

Figure 4: *Qualitative data analysis spiral model adapted from Leedy and Ormrod (2001, p. 161)*

Consistent with Leedy and Ormrod (2001, p. 161), qualitative data analysis is a complex and time consuming process. Much of the data obtained for the analysis process are multifaceted and may simultaneously reflect a number of different meanings. However, by following this spiral model (in Figure 4), these circumstances can be significantly alleviated. An established model or plan allows for a more accurate qualitative data analysis to be performed, effectively reducing the complexity and time of this process.

The data analysis phase will use the data generated and collected from the prototype software as its primary source. The analysis will consider five main factors, as outlined in the previous section: efficiency, accuracy, ease-of-use, and the amount of manual user input required or permitted. Aside from achieving these five main factors, an effective solution should also be robust and handle incomplete or imprecise data without losing performance. This is particularly important to consider when developing a system requiring little or no user input. Since this is the primary goal, a reliable solution must certainly take these considerations into account. Discussed in the next section is the validity and integrity of the research results, including how these relate directly to this research.

4.5 Validity

The integrity of the research results directly correlate to the research validity. In this context, Leedy and Ormrod (2001) suggest that validity describes the precision, significance, and authenticity of the research study as a whole. Since internal and external research validity exists, both must be considered in order to accomplish complete research validity.

As maintained by Cohen and Manion (1994, p. 170-172), cited in Walliman (2001, p. 247), there are several factors that can cause a threat to internal and external validity. Those factors affecting internal validity include history, maturation, statistical regression, testing, instrumentation, selection, and experimental mortality. The factors affecting external validity include vague identification of independent variables, faulty sampling, Hawthorne effect, inadequate *operationalisation* of dependent variables, sensitisation to experimental conditions, and extraneous factors. Further indicated by Walliman (2001, p. 247), a research design's level of sophistication and the extent of control will determine the internal validity of the experimental design. Likewise, Walliman (2001) considers "...the extent of the legitimate generalizability of the results gives a rating for the external validity of the design" (p. 247).

Several strategies are presented by Leedy and Ormrod (2001, p. 106), to obtain internal validity. Of these approaches, the triangulation strategy has been chosen for this study, since it allows both quantitative and qualitative data to be collected simultaneously (Leedy and Ormrod, 2001). The data can then be merged, using the results to best understand the research problem.

In relation to Punch (1998, p. 30), external validity is the extent to which the findings of a study can be generalised. A study's external validity is obtained by applying the technique of replicating data in a different context. Further considered by Leedy and Ormrod (2001), when another researcher, who conducts a similar study in a very different context, reaches similar conclusions to your study, external validity is obtained. Applying this approach will allow the external validity of this study to be demonstrated.

5. DESIGN AND IMPLEMENTATION

The design and implementation of this investigation is discussed under five chronological headings: develop the combined algorithmic procedures, develop the prototype software implementations, generate data from the prototype software, record the statistical data, and provide a final summary of the results obtained. After discussing the design and implementation, chapter six will follow with an in-depth discussion on the results and analysis. Final conclusions for this research are then drawn in chapter seven.

5.1 Develop the Combined Algorithmic Procedures

This research has considered a wide range of possible techniques, in an attempt to reach a final solution that can reliably perform accurate image segmentation with as little user input as possible. Consideration of these techniques has been limited specifically to performing image segmentation on photographs of dolphin dorsal fins. Although specifically aimed at extracting dorsal fins from digital photographs, these methods could also be adapted for other applications, as suggested during the literature review in chapter three.

A number of techniques are explained in relation to how they can be implemented to extract dorsal fins from digital photographs. All techniques discussed in this chapter have been implemented in four prototype software solutions. These are illustrated digitally on the included compact disc media found in Appendix D. All prototype software mentioned during this research has been especially custom-built by the author, to thoroughly demonstrate and prove the various techniques, methods and possible solutions discussed.

As established in the previous chapters, no single automated technique is currently able to perform reliable image segmentation. However, this does not prevent combining several techniques to produce a fairly reliable solution. Various required techniques will need to be applied from the acquisition, pre-processing, and segmentation areas.

5.1.1 Acquiring the Digital Image

Acquiring digital images requires the use of a digital camera or other similar device to capture images. Captured images are downloaded to the computer's memory, using third-party software. The study has designed and implemented prototype software that employs existing image libraries, such as FreeImage, CXImage, and the Sun Microsystems Java Image Library. These libraries enable the prototype software to support current popular image formats (e.g. bmp, gif, jpeg, png, tiff, etc.). After acquiring a digital image, the prototype software loads the acquired image and is initialised for the pre-processing procedures. Many of the pre-processing procedures are also handled by the image libraries mentioned earlier.

5.1.2 Pre-processing

Discussed during the literature review in chapter three, image pre-processing is an important step that must be performed before any kind of image recognition takes place. Under some circumstances one or more image pre-processing routines must also be performed before the image segmentation process. The design and implementation of prototype software for this research considers various pre-processing routines. These routines include edge smoothing, sharpening, blurring, image brightness and contrast, cropping, resizing, flipping the image horizontally and vertically, and converting the image to grey scale and/or negative.

Although designed into the prototype software, the pre-processing routines mentioned above will only be performed at the user's discretion. This is mainly due to the lack of 'intelligence' in the prototype software being unable to determine the exact pre-processing routines to run. Even if the software were programmed with enough 'intelligence' to automatically determine the type of pre-processing required, issues would still exist with the parameters for each pre-processing routine. Therefore, pre-processing has been designed into the prototype software for users to employ at their discretion, as optional facility. These pre-processing routines are made available to assist with enhancing the accuracy of the image segmentation process. They also assist with feature and object extraction procedures. However, most of the design and implementation is focussed primarily on the image segmentation process, as discussed next.

5.1.3 Segmentation

Design of image segmentation methods in the prototype software is based on information generated from the literature review in chapter three. Since various strategies exist for image segmentation, several software prototypes have been designed and implemented. As will be discussed in sections to follow, each design has its advantages and drawbacks. The intent, however, is to demonstrate the advantages of each design. A final solution can then be suggested, which integrates the advantages of each design into one complete package.

Implementation of the first prototype design, allowed an object to be selected using a flood-fill algorithm with a tolerance level. The concept behind this method was to implement a facility very similar to the 'magic-wand' tool found in some professional image editing software products, such as Adobe® Photoshop. However, instead of showing a dynamic selection outlining the area of the image currently selected, this facility flood-filled the area with a consistent colour. The design also includes facilities to zoom in and out on regions of the image. Also provided are tools to undo and redo the selection history. The techniques used in this design include flood-fill with tolerance, edge detection, and a recursive algorithm to refine any rough selection areas. Since it is assumed the desired object will always have similar shades of the same colour (e.g. as in a dorsal fin), this design is possibly a valid solution. However, as will be discussed in the next chapter, various limitations do exist.

The second prototype designed and implemented, uses the intelligent scissors technique. This involves employing the active contour, or snakes, approach and requiring user input to generate seed points. These seed points assist in accurately extracting an object from an image, particularly images that have a very complex background. This has been discussed in more elaborate detail during the literature review in chapter three. Although this technique performs really well and has a high accuracy rating, issues still remain with its level of automation. It also requires fairly accurate fine-motor skills. This technique is discussed further in sections to follow.

A third prototype was designed and implemented to demonstrate a higher level of automation than that provided by the intelligent scissors approach. Although this design employs similar techniques to those in the first prototype, it has some differences. A paint brush selection tool is provided, allowing the user to roughly paint over the desired object. In the case of the dorsal fin, the user operates the mouse to quickly and roughly select areas of the dorsal fin. In doing so, a dictionary of unique colours associated with the object of interest is created. The design also employs a flood-fill algorithm with a tolerance level. After roughly painting over the object of interest, the object will be extracted, starting at the points where the user made the rough selection. The extraction process uses flood-fill with a tolerance level, based on the unique pixel dictionary generated from the user selection. This allows the entire object to be accurately extracted from the image. Although the theory for this design is attractive, it too has implementation issues, discussed more extensively in later sections.

The final software prototype designed and implemented is almost fully automated. This design employs object extraction techniques, using grey-level segmentation concepts with tolerance levels. The design also adapts techniques to detect edges and inconsistent objects. However, it relies on the assumption that the object being extracted is greyish in colour and is the largest object in the image. This assumption renders the design ineffective if the user inputs a greyscale image. However, if it is assumed that all photographs will be colour, and all dorsal fins will consist entirely of grey shades, this design may prove very efficient and accurate. The concept is to find the largest object in the image, made up of grey shades. Edge detection is performed to help select the single most significant surface area of grey shades. By performing this process, smaller objects consisting of grey shades may also be selected. However, a simplified level of intelligence is also designed into the software to remove any selected objects that are smaller and not part of the largest object. Tests on a prototype implementation of this design have proven reliable. However, various issues exist that may flaw this design under some circumstances. These are discussed in more detail during following sections.

5.2 Develop Prototype Software Implementations

5.2.1 Flood Filling with a Tolerance Level

As discussed in the previous section, this prototype design allows an object to be extracted using a flood-fill technique that employs a user-defined colour tolerance level. In this design, the user operates the mouse to fill the object with a consistent colour. This design requires the consistent colour to be unique, not existing anywhere in the original photograph. After filling the object, the extraction process will remove everything from the image except the area consisting of the selection colour. It then performs a customised recursive object refinement algorithm to remove rough selection areas. For example, the user does not have to accurately select every pixel in the object. Rather, the recursive object refinement algorithm can be relied on to touch-up any small areas inside the object that have been missed out from the selection. This allows for a very fast object selection and extraction process. However, as discussed during the analysis, this design presents several issues. These mainly exist with photographs that are not of reasonable quality and where the dorsal fin is very similar in colour to its surrounding background. Figure 5 illustrates this design, demonstrating the four main processes employed to extract an object from an image.

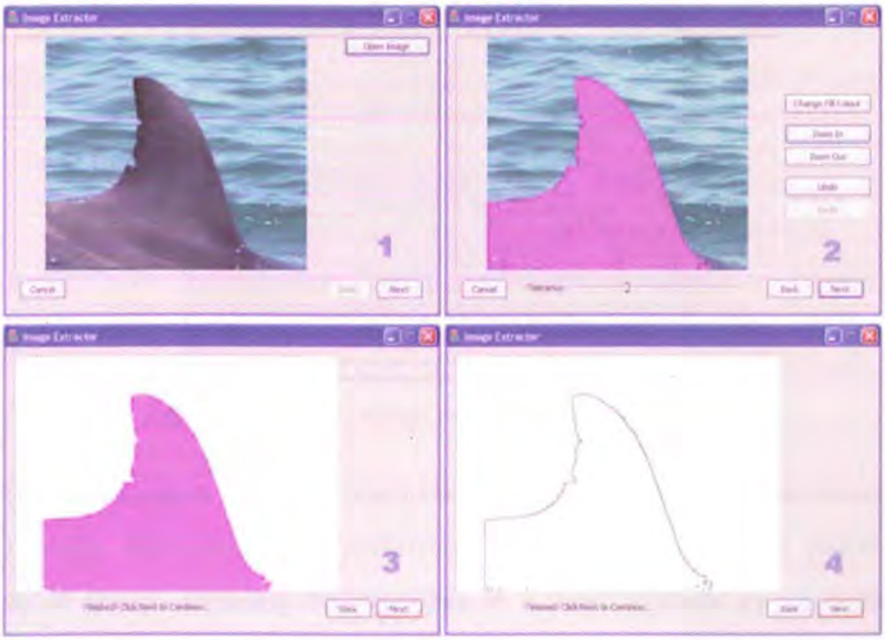

Figure 5: *Prototype design one, flood filling with tolerance level*

5.2.2 Intelligent Scissors

The intelligent scissors prototype was designed and implemented simply to test the concept. The prototype software demonstrates a high level of accuracy in extracting the desired object. However, issues remain in regard to automation. As discussed in the previous section, this design employs active contours, or snakes, along with user defined seed points to extract an object. Since it employs active contours, tracing the outline of the image is relatively simple. If tracing starts to select inappropriate parts of the image, the user can create a seed point by clicking the location on the object edge where the selection starts to divert. This process is fairly straight forward and relatively time efficient. However, it does require rather accurate fine motor skills. Since it relies considerably on the user's input, this design is significantly less automated. It should therefore be used as a compromise over a more automated approach. Figure 6 illustrates an implementation using the intelligent scissors technique.

Figure 6: *Prototype design two, intelligent scissors*

This technique is preferred when attempting to accurately extract an object from an image that cannot be performed using more automated processes. Therefore, it should certainly be provided in a final solution as an optional facility, when alternative automated methods do not generate the desired results.

5.2.3 User Defined Rough Object Selection

This design is very similar to the first prototype. It provides a higher level of automation than the intelligent scissors prototype. Numerous tools for image pre-processing are also provided, allowing the user to enhance the content of the image for more reliable segmentation results. Pre-processing tools include image brightness and contrast, horizontal and vertical flipping, greyscale and negative conversions, sharpening, and blurring. In addition, this design also implements 'undo' and 'redo' facilities, enabling the user to navigate through the history of previous pre-processing operations.

A paint brush tool allows the user to quickly and roughly select the object for extraction. This is performed by operating the mouse to paint regions inside the object. By doing so, unique pixels and corresponding (x,y) coordinate locations are recorded in a dictionary. This assists in accurately selecting the object using edge detection and flood-filling techniques with tolerance levels. Although effective, this design demonstrates some issues that may produce undesired results depending on the image. For example, it may fail when the surrounding background is similar in colour to the object being selected, discussed in more detail in following sections. The process this design takes to extract an object from an image is illustrated in Figure 7.

Figure 7: *Prototype design three, user-defined rough object selection*

5.2.4 Grey-Level Tolerance Segmentation with Edge Detection

This final design almost provides a fully automated segmentation solution, by employing object extraction techniques, using grey-level segmentation concepts with tolerance levels. This design has the ability to accurately detect and extract a dorsal fin from a photograph. The design operates on the assumption that the main object in the photograph will be the dorsal fin, having a greyish texture. Applying grey-level segmentation with a tolerance level, along with an adapted edge detection technique, proved to accurately extract a variety of dorsal fins from photographs. The extraction process requires no initial user input to identify the object (dorsal fin). However, optional user facilities are provided, allowing the grey-level tolerance to be adjusted if desired. Also provided, are facilities to quickly and easily customise the red, green, blue, and alpha tolerance levels. Figure 8 illustrates this design in operation.

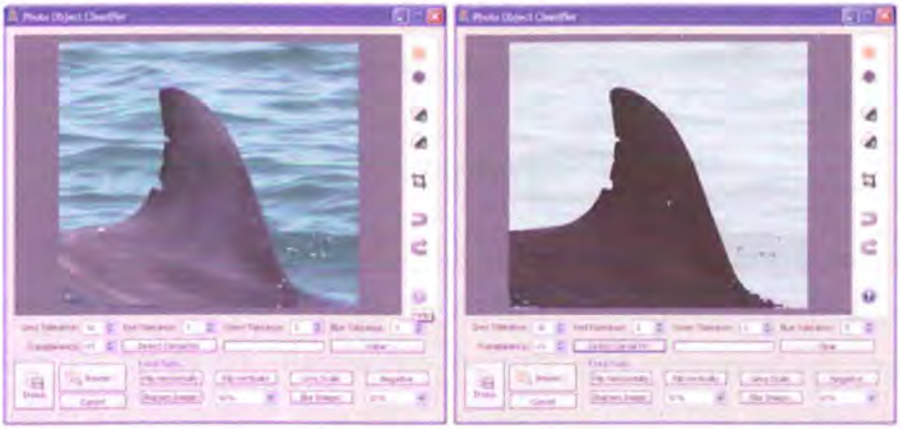

Figure 8: *Final design, grey-level tolerance segmentation with edge detection*

Automation operates on several assumptions, as mentioned previously. First, it assumes that the main, most significant, object in the photograph will be the object to extract (e.g. dorsal fin). It also assumes that this object will consist of a greyish texture. These assumptions are valid, since this design is specifically intended for the extraction of dorsal fins from photographs. To begin, the design performs a grey-level segmentation routine on the photograph, in conjunction with an adapted edge detection method. Grey tolerance allows the design to have a sensitivity level, providing higher accuracy and reducing the number of grey objects selected. The grey tolerance level is automatically adjusted to provide the best results. Automatic adjustment is based primarily on the properties of the edge detection routine.

After detecting the main grey-level objects in the photograph, a second process is built into the design to detect the largest of these objects. All other selected objects will then be deselected and ignored. A transparency level is also built into the design, to assist the user with visually affirming the accuracy of the object extraction. Since the automation process allows object extraction to be performed in real time, the user can see the results almost immediately. The transparency level allows the user to visualise, and optionally adjust, the opacity of the area not selected for extraction. An optional facility to monochrome the selected object provides additional flexibility, allowing it to be easily visualised. Although this design proves very reliable under the right conditions, it also has some unpredictable issues surrounding its level of automation and accuracy. These issues are discussed in further detail in following sections.

5.3 Generate Data from Prototypes

Data has been generated from all four prototype designs. In testing the prototypes, various images of dolphin dorsal fins were inputted into the prototype software for processing. Ratings on the efficiency, accuracy, and level of automation were then made. Generated data for each of the four prototype designs is outlined in following sections.

To test the prototype software, the test case design process outlined by Sommerville (2004) has been followed. Summerville (2004) suggests that "...the goal of the test case design process is to create a set of test cases that are effective in discovering program defects and showing that the system meets its requirements" (p. 551). A test case is design by selecting a feature or component to test, identify its required inputs and record the resulting outputs. Sommerville (2004, p. 552) suggests three different approaches that can be taken in designing a test case. Of these, the *Requirements-based Testing* approach has been taken for this study. Appendix B outlines the test design and procedures used. This test case strategy, adapted from Sommerville (2004), is also supported by Pressman (2005), which reinforces the decision to apply this approach.

5.3.1 Data Generated from Prototype Design One

The following figures illustrate the four photographs used and the processes taken to extract the dorsal fins from each of the photographs. Each subsequent table shows the statistical data extracted from the test process illustrated in the associated figure.

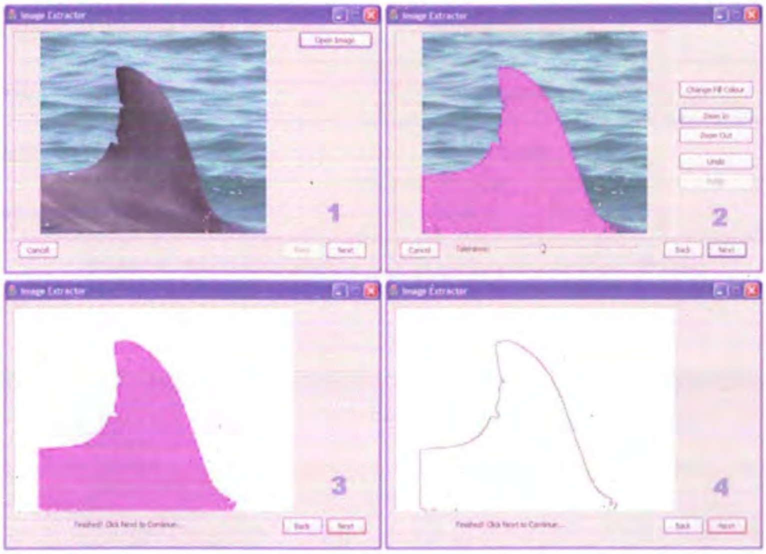

Figure 9: *Prototype design one, illustration of 1^{st} data generation test*

Required User Input:	20 mouse clicks
User Input Time:	~25 seconds
Auto-Extraction Time:	~2 seconds
Accuracy Rating:	70%

Table 1: *Prototype design one, data generated from 1^{st} test*

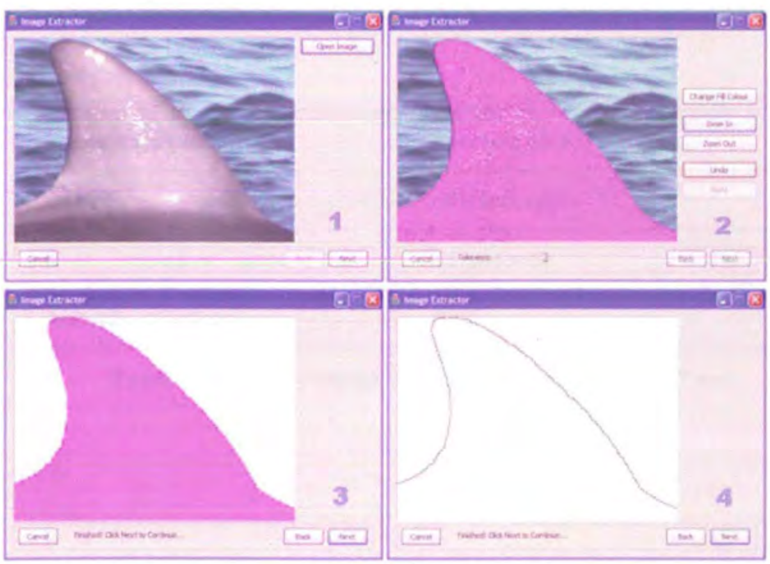

Figure 10: *Prototype design one, illustration of 2^{nd} data generation test*

Required User Input:	30 mouse clicks
User Input Time:	~40 seconds
Auto-Extraction Time:	~2 seconds
Accuracy Rating:	80%

Table 2: *Prototype design one, data generated from 2nd test*

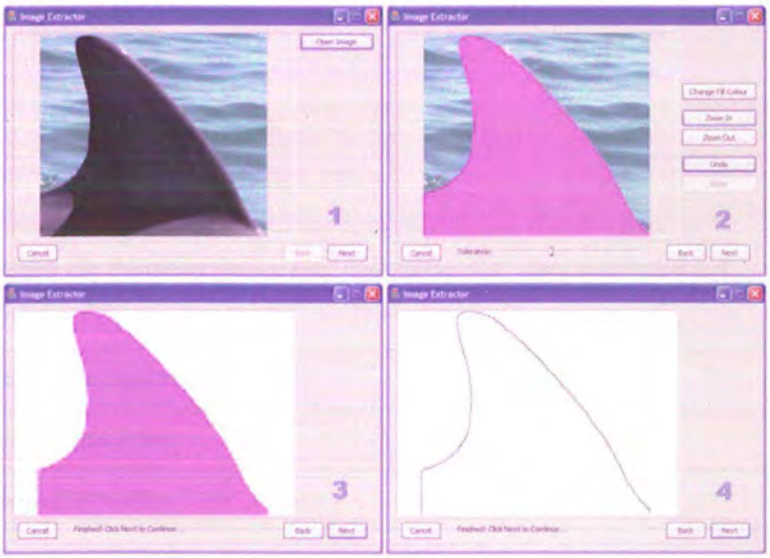

Figure 11: *Prototype design one, illustration of 3rd data generation test*

Required User Input:	6 mouse clicks
User Input Time:	~15 seconds
Auto-Extraction Time:	~2 seconds
Accuracy Rating:	80%

Table 3: *Prototype design one, data generated from 3rd test*

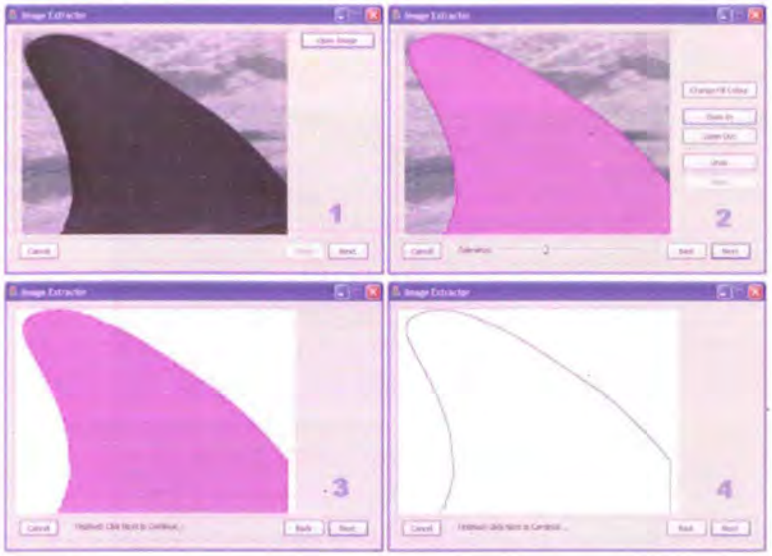

Figure 12: *Prototype design one, illustration of 4^{th} data generation test*

Required User Input:	4 mouse clicks
User Input Time:	~8 seconds
Auto-Extraction Time:	~2 seconds
Accuracy Rating:	90%

Table 4: *Prototype design one, data generated from 4^{th} test*

5.3.2 Data Generated from Prototype Design Two

The following figures illustrate the four photographs used and the processes taken to extract the dorsal fins from each photograph. Each table shows the statistical data extracted from the test process, illustrated in the related figure. These tests are in relation to the *intelligent scissor image segmentation* technique. Although this design demands significantly more manual user input and time, to the other more automated techniques, it has the advantage of accuracy and consistent reliability. As suggested in previous sections, during the implementation of a final software solution, this design should certainly be considered as an optional feature. This provides the user with complete control over the image segmentation process, while retaining as much automation as possible.

Figure 13: *Prototype design two, illustration of 1st data generation test*

Required User Input:	9 seeds (mouse clicks)
User Input Time:	~25 seconds to select
Auto-Extraction Time:	nil
Accuracy Rating:	100% (based on user input)

Table 5: *Prototype design two, data generated from 1st test*

Figure 14: *Prototype design two, illustration of 2nd data generation test*

Required User Input:	6 seeds (mouse clicks)
User Input Time:	~15 seconds to select
Auto-Extraction Time:	nil
Accuracy Rating:	100% (based on user input)

Table 6: *Prototype design two, data generated from 2nd test*

Figure 15: *Prototype design two, illustration of 3rd data generation test*

Required User Input:	22 seeds (mouse clicks)
User Input Time:	~45 seconds to select
Auto-Extraction Time:	nil
Accuracy Rating:	100% (based on user input)

Table 7: *Prototype design two, data generated from 3rd test*

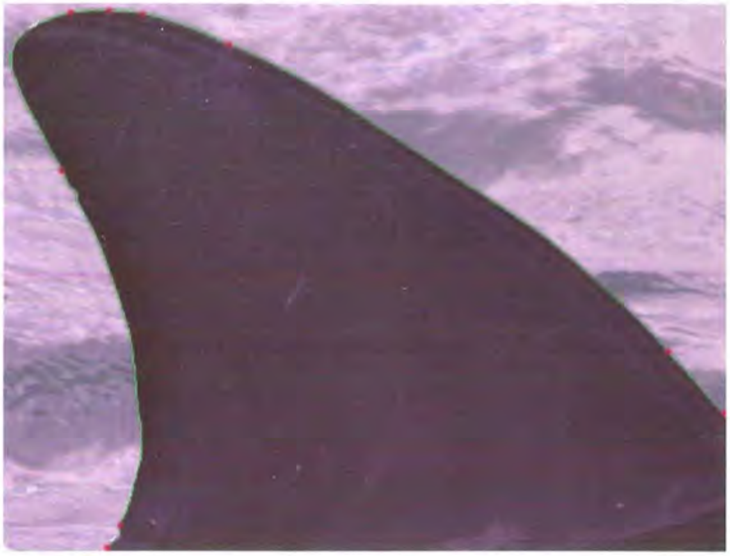

Figure 16: *Prototype design two, illustration of 4th data generation test*

Required User Input:	9 seeds (mouse clicks)
User Input Time:	~15 seconds to select
Auto-Extraction Time:	nil
Accuracy Rating:	100% (based on user input)

Table 8: *Prototype design two, data generated from 4th test*

5.3.3 Data Generated from Prototype Design Three

The following figures illustrate the four photographs used and the processes taken to extract the dorsal fins from each photograph. Each table shows the statistical data extracted from the test process, illustrated in the related figure. These tests are in relation to the *user-defined rough object selection* technique. This technique still requires user input however, it is significantly less demanding than that of the second (previous) design.

Figure 17: *Prototype design three, illustration of 1st data generation test*

Required User Input:	1 mouse click and drag to paint rough selection of object
User Input Time:	~6 seconds to select
Auto-Extraction Time:	~20 seconds
Accuracy Rating:	70%

Table 9: *Prototype design three, data generated from 1st test*

Figure 18: *Prototype design three, illustration of 2nd data generation test*

Required User Input:	4 mouse clicks and drags to paint rough selection of object
User Input Time:	~4 seconds to select
Auto-Extraction Time:	~25 seconds
Accuracy Rating:	60%

Table 10: *Prototype design three, data generated from 2nd test*

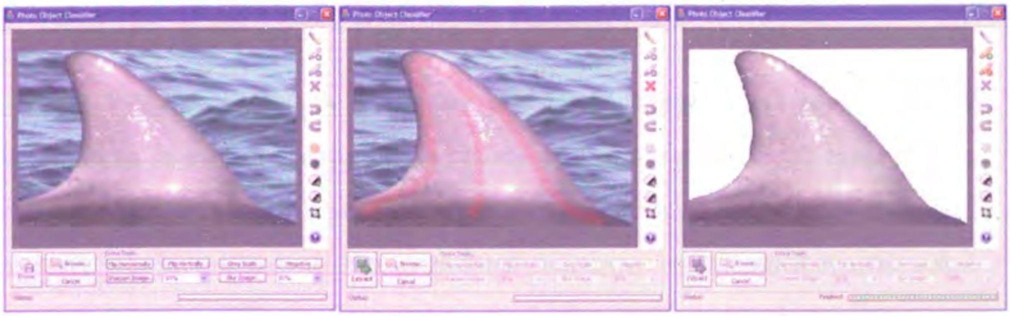

Figure 19: *Prototype design three, illustration of 3rd data generation test*

Required User Input:	3 mouse clicks and drags to paint rough selection of object
User Input Time:	~4 seconds to select
Auto-Extraction Time:	~25 seconds
Accuracy Rating:	70%

Table 11: *Prototype design three, data generated from 3rd test*

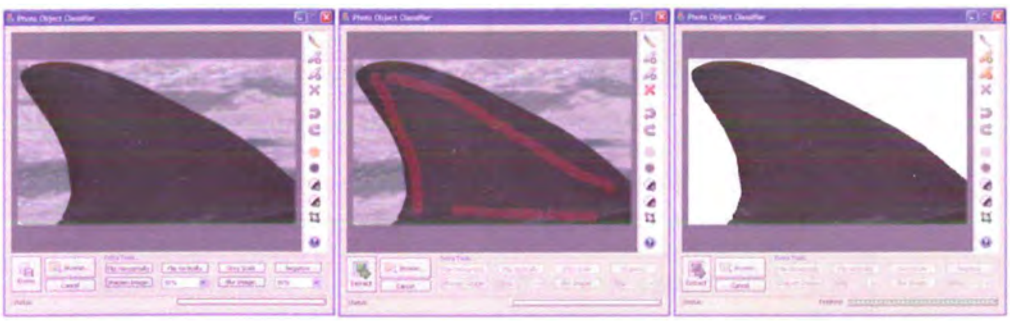

Figure 20: *Prototype design three, illustration of 4th data generation test*

Required User Input:	3 mouse clicks and drags to paint rough selection of object
User Input Time:	~4 seconds to select
Auto-Extraction Time:	~20 seconds
Accuracy Rating:	80%

Table 12: *Prototype design three, data generated from 4th test*

5.3.4 Data Generated from Prototype Design Four

The following figures illustrate the four photographs used and the processes taken to extract the dorsal fins from each photograph. Each table shows the statistical data extracted from the test process, illustrated in the related figure. These tests are in relation to the *grey-level tolerance segmentation with edge detection* technique. This technique requires very little or no user input and produces fairly reliable results. However, the technique will not produce desired results unless photographs meet certain criteria. The following four tests all performed fairly reliable though this is not always the case, further discussed.

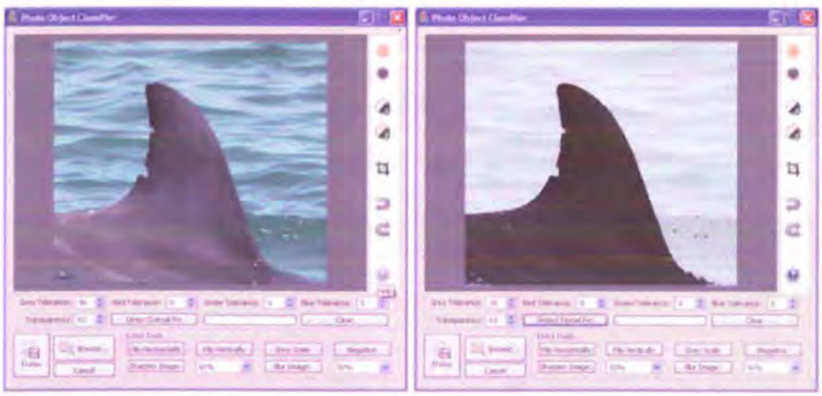

Figure 21: *Prototype design four, illustration of 1st data generation test*

Required User Input:	1 click, 0 tolerance adjustments
User Input Time:	nil
Auto-Extraction Time:	~1 second
Accuracy Rating:	90%

Table 13: *Prototype design four, data generated from 1st test*

Figure 22: *Prototype design four, illustration of 2^{nd} data generation test*

Required User Input:	1 click, 0 tolerance adjustments
User Input Time:	nil
Auto-Extraction Time:	~1 second
Accuracy Rating:	90%

Table 14: *Prototype design four, data generated from 2^{nd} test*

Figure 23: *Prototype design four, illustration of 3^{rd} data generation test*

Required User Input:	3 clicks, 2 tolerance adjustments
User Input Time:	~8 seconds
Auto-Extraction Time:	~1 second
Accuracy Rating:	90%

Table 15: *Prototype design four, data generated from 3^{rd} test*

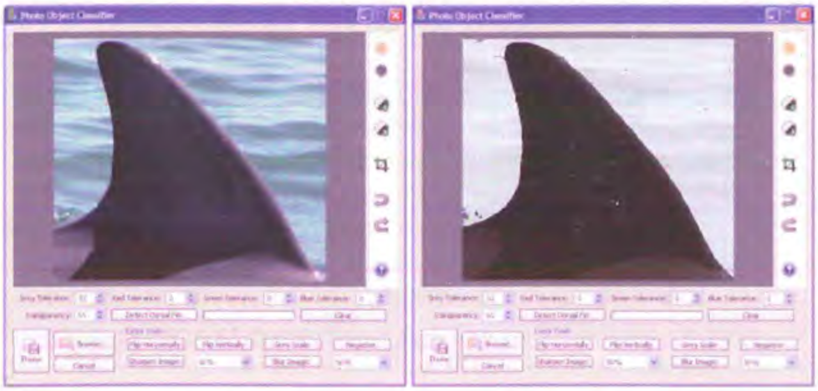

Figure 24: *Prototype design four, illustration of 4th data generation test*

Required User Input:	5 clicks, 4 tolerance adjustments
User Input Time:	~15 seconds
Auto-Extraction Time:	~1 second
Accuracy Rating:	70%

Table 16: *Prototype design four, data generated from 4th test*

5.4 Record Statistical Data

Collected statistical data from tests made on the prototype software designs are recorded in spreadsheet format. This allows the data to be easily referenced and analysed during the results and analysis stage. Tables 17 to 20 give the typical data, collected and organised in spreadsheet format. This data was collected from the tests run on the four prototype designs described earlier.

Data Collected from Tests on Prototype Design One				
	Required User Input	**User Input Time**	**Auto-Extraction Time**	**Accuracy Rating**
Test 1:	20 mouse clicks	~25 seconds	~2 seconds	70%
Test 2:	30 mouse clicks	~40 seconds	~2 seconds	80%
Test 3:	6 mouse clicks	~15 seconds	~2 seconds	80%
Test 4:	4 mouse clicks	~8 seconds	~2 seconds	90%
Overall Result:	*avg. 15 mouse clicks*	*avg. ~22 seconds*	*avg. ~2 seconds*	*avg. 80%*

Table 17: *Typical data collected from tests on 1st prototype design*

Data Collected from Tests on Prototype Design Two				
	Required User Input	**User Input Time**	**Auto-Extraction Time**	**Accuracy Rating**
Test 1:	9 seeds (mouse clicks)	~25 seconds	nil	100%
Test 2:	6 seeds (mouse clicks)	~15 seconds	nil	100%
Test 3:	22 seeds (mouse clicks)	~45 seconds	nil	100%
Test 4:	9 seeds (mouse clicks)	~15 seconds	nil	100%
Overall Result:	*avg. ~11 mouse clicks*	*avg. ~25 seconds*	*avg. nil*	*avg. 100%*

Table 18: *Typical data collected from tests on 2nd prototype design*

Data Collected from Tests on Prototype Design Three				
	Required User Input	**User Input Time**	**Auto-Extraction Time**	**Accuracy Rating**
Test 1:	1 mouse click/drag	~6 seconds	~20 seconds	70%
Test 2:	4 mouse clicks/drags	~4 seconds	~25 seconds	60%
Test 3:	3 mouse clicks/drags	~4 seconds	~25 seconds	70%
Test 4:	3 mouse clicks/drags	~4 seconds	~20 seconds	80%
Overall Result:	*avg. ~3 mouse clicks/drags*	*avg. ~4 seconds*	*avg. ~22 seconds*	*avg. 70%*

Table 19: *Typical data collected from tests on 3rd prototype design*

Data Collected from Tests on Prototype Design Four				
	Required User Input	**User Input Time**	**Auto-Extraction Time**	**Accuracy Rating**
Test 1:	1 click, 0 tol. adj.	~25 seconds	~2 seconds	70%
Test 2:	1 click, 0 tol. adj.	~40 seconds	~2 seconds	80%
Test 3:	3 clicks, 2 tol. adj.	~15 seconds	~2 seconds	80%
Test 4:	5 clicks, 4 tol. adj.	~8 seconds	~2 seconds	90%
Overall Result:	*avg. ~2 clicks, ~1 tol. adj.*	*avg. ~6 seconds*	*avg. ~1 seconds*	*avg. 85%*

Table 20: *Typical data collected from tests on 4th prototype design*

In addition to data collected from tests performed on the prototype designs, survey data has also been collected. The survey data was generated from consistent feedback given by various marine research centres around the world. The data relates to current photo-identification software available to marine research centres, and areas that need further development. This data is tabled in Appendix A. An analysis of the data collected from tests on the prototype software and from the survey is provided in the next chapter. Results of this analysis are also discussed. The next section concludes with a summary of the data and results attained from the statistical data collection process.

5.5 Summary of Results Attained

Data collected from the test prototypes includes the amount of user input required, time taken for the user to give that input, time taken for the automatic object extraction process, and the accuracy rating. This data is collected from four tests run on each prototype. An overall averaging result for each test is also calculated. Additional data collected for this research, includes survey feedback from participating marine research centres from around the world. This feedback includes discussion on the most frequently used software systems, properties of collected images, required accuracy and efficiency, and the amount of manual user input permissible.

6. RESULTS AND ANALYSIS

This chapter provides on overview of the data analysis process and discusses the results obtained. The structure first discusses the data analysis process, and then provides an overview of the quantitative and qualitative results attained from the analysis. A final overall summary then provides a comprehensive conclusion to this chapter. Several charts given in the next section also help illustrate the data analysis results for this study.

6.1 Analysis of Collected Data

Provided in this section is an analysis of the data collected from two sources. The first is survey feedback, provided by various participating marine research centres from around the world. The second is an analysis of the data collected from tests performed on four prototype designs, implemented for this study. The test case design was based on a stringent set of guidelines, outlined in Appendix B. A large portion of the data analysis results and conclusions have been compared and verified against relevant information presented by Sonka, et al. (1999). This has assisted in providing substantiating arguments for the final conclusions presented. The data analysis has been divided into two sub-sections that follow.

6.1.1 Analysis of Data Collected from Survey

The survey feedback provided a range of data, detailing the general expectations of marine researchers, in regard to automated photo-identification systems. Based on the feedback returned from various marine research centres, the following analysis has been made. The raw data used in the analysis can be found in Appendix A.

The analysis initially tables the feedback provided and categorises it into two major sections. The first section identifies general software package requirements. More specifically, this section aims to determine the general preference for integrating a customised database management system with an image recognition component. Table 21 gives the actual feedback from the survey participants, also illustrated in Figure 25. An average is then calculated, based on the feedback given. This is used to determine the general consensus of each question in this section. Each question and the provision for participant feedback are illustrated in screen shots of the actual survey form under Appendix C.

General Software Package Requirements				
Participant...	**Question 1**	**Question 2**	**Question 3**	**Question 4**
1	3	3	3	3
2	2	2	2	1
3	3	3	2	2
4	3	3	3	2
5	3	3	3	3
6	3	3	3	3
7	3	2	2	2
8	3	3	3	3
9	3	3	3	2
10	3	3	3	3
Result:	***3***	***3***	***3***	***2***

Table 21: *Survey feedback on general software package preferences*

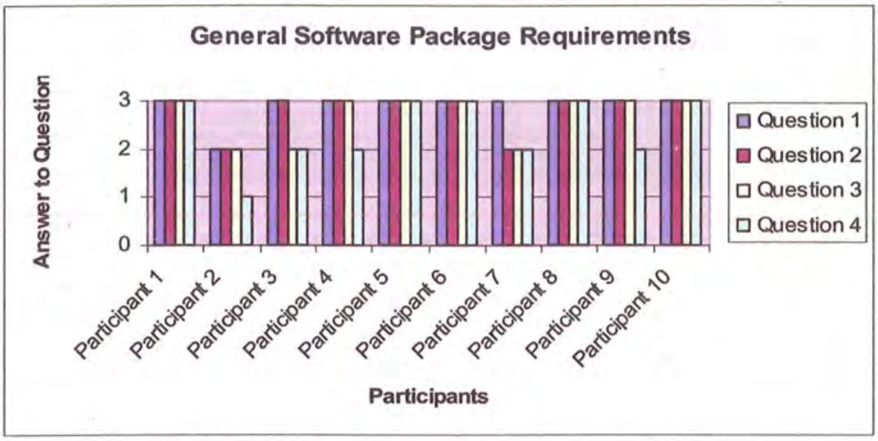

Figure 25: *Survey feedback on general software package preferences*

The second section identifies the general requirements for an image recognition component. More specifically, this section aims to determine the level of accuracy, efficiency, user-friendliness, and amount of manual data input expected. Table 22 gives the actual feedback from the survey participants, also illustrated in Figure 26. An average is also calculated for this section, based on the feedback given. Again, this is used to determine the general consensus of each question. Screen shots of the actual survey form under Appendix C illustrate the questions asked and the options provided for participant feedback.

General Requirements for Image Recognition Software				
Participant...	**Question 5**	**Question 6**	**Question 7**	**Question 8**
1	3	3	2	2
2	3	2	2	1
3	3	2	2	2
4	3	2	3	3
5	3	2	2	2
6	3	2	2	1
7	3	3	3	2
8	3	3	3	3
9	3	3	3	3
10	3	3	3	3
Result:	***3***	***3***	***3***	***2***

Table 22: *Survey feedback on general image recognition requirements*

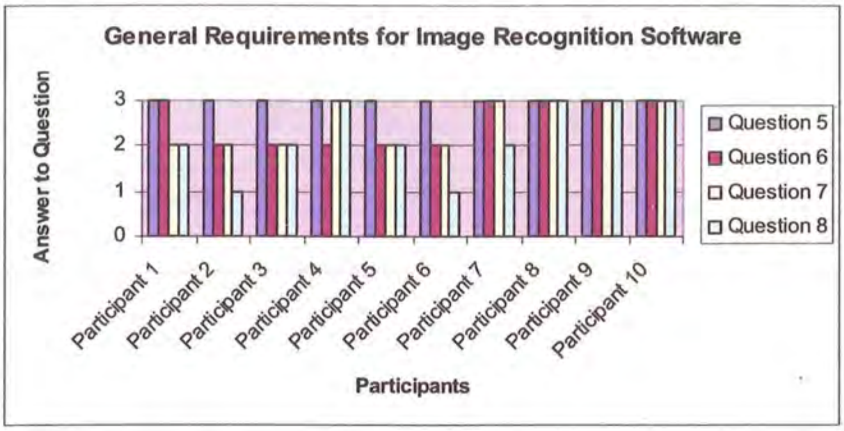

Figure 26: *Survey feedback on general image recognition requirements*

The analysis given in Table 21 and 22 uses numerical ranking criteria to produce the final results for the analysis. The ranking criteria use a value of 1, 2, or 3, where 1 is the lowest preference and 3 is the highest. This is more easily understood by examining the illustration of the actual survey form under Appendix C. From this analysis, the following results have been concluded.

Image recognition software, that identifies cetacean specimens, is regarded by all marine research centres, who participated in the survey, as invaluable. Having this integrated into a customised database management system is also regarded as very useful. Analysis on feedback results shows that the availability of such software would significantly enhance the productivity of marine research. Furthermore, if such software were available, it would assist in reducing the manual data management time somewhat. The accuracy, efficiency, and user-friendliness of the image recognition software are also considered very important. Although the minimisation of manual data input is also considered important, it is not essential. These conclusions, based on the analysis results, agree with similar previous studies (Arrabi, et al., 2000; Debure and Russel, 2001; Hillman, et al., 2002; and Kreho, et al., 1999). Figure 27 illustrates the overall analysis results for the feedback given in the survey.

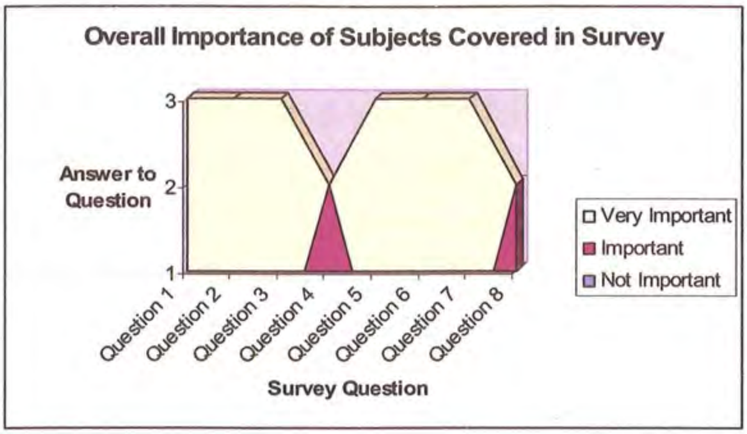

Figure 27: *Importance of subjects covered in survey, as per the analysis conclusions*

6.1.2 Analysis of Data Collected from Tests on Prototypes

Tests performed on the four prototype designs have provided a range of data. This data provides the statistics required to analyse and determine the best image segmentation solution. Raw data collected from these test cases were previously outlined in chapter five. Table 23 and Figure 28 illustrate the overall performance of each prototype design.

	Prototype 1	Prototype 2	Prototype 3	Prototype 4
~ User Input (mouse clicks):	15	11	3	3
~ User Input Time (seconds):	22	25	4	6
~ Auto Extraction Time (seconds):	2	0	22	1
Accuracy Rating:	80%	100%	70%	85%

Table 23: *Overall performance of each prototype design*

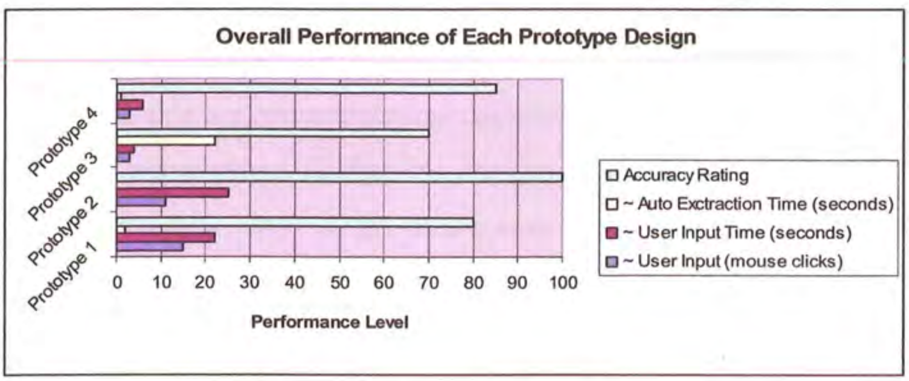

Figure 28: *Overall performance for each prototype design*

As depicted in Figure 28, the second prototype design has the highest accuracy rating. However, it also demands the highest manual user input time and the second highest amount of manual input. As discussed in previous sections, although this design is very reliable, it does not provide the level of automation expected. This analysis result is also supported by similar previous studies, such as that from Arrabi, et al. (2000) and Kreho, et al. (1999). As can be seen from the results shown in Table 23 and Figure 28, the fourth prototype design has the highest overall performance level. This design has the highest accuracy rating and demands the least manual user input. This design also has the lowest automatic extraction time rating and the second lowest rating for manual user input time. However, as discussed in previous chapters, this design has limitations that can significantly impact on the analysis results outlined in this section.

Since no single automated method currently exists to reliably perform image segmentation, several methods should be combined to provide a more comprehensive solution. This has been carefully pointed out and proven in previous chapters. Comparable conclusions have also been drawn from other previous similar studies, such as that from Hillman, et al. (2002), Arrabi, et al. (2000), Sonka, et al. (1999), and Kreho, et al. (1999). For example, consider combining the techniques employed in prototype designs two, three, and four. Under most circumstances, the automated approach can be used to perform the image segmentation. If the automated approach fails, a second option is available (prototype design two) to assist in accurately extracting the image.

Although this is a compromise, as considered by Sonka, et al. (1999), it is not regarded as inconvenient. Rather, this solution is considered an acceptable and very reliable solution, since it gives the user complete control over image segmentation accuracy. The previous section of this analysis provides the evidence supporting this conclusion, by the analysis of the survey feedback results provided by various marine research centres.

6.2 Summary of Results Obtained

An analysis of the survey feedback data has shown that marine research centres regard image recognition software, which identifies cetacean specimens, as highly valuable. They also suggest it would be very useful to have this software integrated into a customised database management system. Also considered as very important, is the accuracy, efficiency, and user-friendliness of the image recognition component. Although not essential, any automated features that help minimise manual data input is considered important and quite beneficial.

Further data analysis on test-case results from the four prototype designs has provided defensive conclusions suggesting that several methods should be combined for a complete solution. Data analysis on the results obtained from the test-cases shows the performance of each prototype design. Although several designs exhibit very good performance levels, each one has limitations, as discussed in previous sections. The conclusion of the analysis therefore suggests combining the best performing designs for a complete solution. This suggestion is also supported by Sonka, et al. (1999), stating that there is currently no single, independent method that is able to perform reliable automated image segmentation. This is especially the case when dealing with natural photographic images that have an unpredictably complex background, including any number of varying objects in the image. The following chapter discusses these conclusions and any limitations in further detail, also providing additional ground for further research and development.

7. CONCLUSIONS AND RECOMMENDATIONS

This investigation has conducted an analysis on the specific requirements of marine research centres, to develop an automated photo-identification software system. In particular, this study focuses on the image segmentation process, since this is generally regarded as the area currently hindering the progression of automated image recognition.

Four prototypes have therefore been designed and implemented. Test-cases on these prototypes have enabled performance levels of each design to be measured and recorded. From these data analysis results, conclusions have been drawn, suggesting a possible solution for reliable image segmentation that is as automated as possible. Different designs implemented include flood-filling with a tolerance level, intelligent scissors, user-defined rough object selection, and automated grey-level tolerance segmentation with edge detection.

The primary research question guiding this investigation was: *Is there an effective solution for implementing an intelligent and accurate software system facilitating automatic photo-identification of cetaceans, such as whales and dolphins?* In order to address this research question, it has also been necessary to address sub-questions such as the level of *intelligence*, *accuracy*, and *automation* required. These research questions, including the outcomes of this investigation, limitations, and areas requiring further research, are addressed in the following sub-sections.

7.1 Outcomes of this Research

An initial survey conducted for this investigation has shown that there is a lack in available software assisting marine researchers with the photo-identification process of individual cetacean specimens. According to feedback provided by various marine research centres, existing software solutions are inaccurate and/or unacceptably labour intensive.

According to data analysis results, marine researchers consider intelligence for automation to be an important factor, however it is not considered essential. Accuracy is regarded as a very important attribute, which must be considered in the design. As established in previous chapters, a fully automated image segmentation solution is currently an unsolved issue. Therefore, a semi-automated system needs to be developed as a compromise. According to the analysis results, marine researchers expect image recognition systems to be accurate, efficient, and user-friendly. Preferably, such software should be developed as a component integrated into a customised database management system. It appears that a generalised, fully automated photo-identification solution facilitating any research field is still a long way of.

An analysis on the test-case results obtained from the prototype designs have assisted in developing conclusions pertaining to the concept of combining several methods for a complete solution. The analysis has shown that several prototype designs exhibit very good performance levels. However, due to the high possibilities for inflexibility and inaccuracy of each design, no single design can be implemented as an independent solution. To overcome these issues, it is suggested that the best performing designs be combined. This enables complete flexibility and accuracy for the user.

Analysis results obtained from this investigation have guided the conclusions as follows. Automated grey-level tolerance segmentation with edge detection should be further developed and enhanced to provide the highest possible performance. This method should be designed into an integrated image recognition software solution as the first option for image segmentation. In addition, the intelligent scissors method should be further enhanced to provide as much automation as possible, reducing the amount of user input required. This method should be made available as a second option if the first, more automated, approach fails to produce acceptable results for certain images.

Arguably, a complete solution to automate the photo-identification process of cetacean specimens is possible. However, results of this investigation suggest that a fully automated solution is currently not possible. Instead, a semi-automated solution must be considered as a compromise, incorporating as much automation as possible. In addition, facilities must be provided that allow the user control over the input for complete flexibility and reliable accuracy.

7.2 Limitations

This investigation has successfully addressed the research questions, although the following limitations are recognised. Analysis of the survey feedback is limited to results given by ten participants. However, since participants are located in key regions of the world, and internationally regarded as significant contributors to marine research, the results are considered fairly reliable. Nonetheless, this limitation has been observed and it is understood that a higher number of survey participants could generate more reliable analysis results.

This study is also limited to the investigation of four specific methods for image segmentation. Preferably, a complete study of this subject should consider all current relative methods. Testing of the four image segmentation methods is also limited. In addition, only prototype software has been designed and implemented. Testing prototype software can produce less reliable results, as opposed to fully implemented designs. However, for the purpose of this investigation, these limitations are considered trivial, due to its nature and intention.

7.3 Recommendations & Further Work

The following recommendations and suggestions for further work are outlined as a result of this investigation. Each of the image segmentation methods investigated in this study demonstrated attractive performance levels in one or more areas. Although it is understood that each method also portrays varying limitations, further research and development could overcome many of these limitations. It is also suggested that additional image segmentation techniques be explored for a more comprehensive study. Additional prototypes could also be designed and/or enhanced for further testing. Further test-case scenarios could provide a wider set of analysis results. Additional analysis strategies on these analysis results could also expose additional areas requiring further research and development.

Additional surveys and correspondence conducted with a wider variety of marine research organisations could expose additional areas requiring investigation. Furthermore, additional work is required to fully support the arguments outlined in this study's conclusions. For instance, a complete software system, combining several methods for image segmentation, should be designed and implemented. This should also be incorporated into a scalable software system that integrates image recognition features with a database management solution. Testing could then be opened to more marine research centres. This would generate a more significant variety of analysis results and provide added conclusions for further development. These recommendations and suggestions for further work are considered quite extensive and could produce a more advanced and reliable solution.

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APPENDICES

Appendix A – Feedback from Marine Research Centres

This appendix outlines the feedback provided by various marine research centres who participated in a survey conducted for this study. The feedback has assisted in identifying the various areas that require further development. Specific questions that have assisted in identifying areas that need attention include image segmentation and recognition accuracy, efficiency, ease-of-use, user-friendliness, and type of software currently being used.

Name: Dr Kevin Robinson
Position: Director
Department: Cetacean Research & Rescue Unit (CRRU)
Country: Scotland, U.K.
Comments: The most difficult element of an automated retrieval system is the development of a component that might be useful for matching the more difficult, subtly marked animals, particularly juveniles. I am not aware of any software that is able to reliably find individuals by dorsal shape as all appear to focus only on position of nicks. I would very much like to receive an electronic copy of your final thesis.

Q1: How valuable would software package that accurately identifies and matches cetacean specimens from collection of digital photographs be?	Very Valuable
Q2: How useful would this software be, if it was integrated with user-friendly data management and retrieval, statistical data analysis, and report generation facilities?	Very Useful
Q3: If you had access to this software, do you believe it would enhance the productivity of your research?	Considerably
Q4: Would this reduce data management time?	Considerably
Q5: How important do you regard accuracy of image recognition and matching abilities of the software?	Very Important
Q6: How important do you regard speed efficiency within the software?	Very Important
Q7: How important do you regard ease-of-use and user-friendliness of the user interface?	Important
Q8: How important do you regard minimisation of manual data input (i.e. more	Important

automation)?	
Q9: Do you know of or use software, which has similar facilities to those previously mentioned?	Yes

Name: Mr Mason Weinrich
Position: Executive Director and Chief Scientist
Department: The Whale Center of New England
Country: U.S.A.
Comments: *nil*

Q1: How valuable would software package that accurately identifies and matches cetacean specimens from collection of digital photographs be?	Valuable
Q2: How useful would this software be, if it was integrated with user-friendly data management and retrieval, statistical data analysis, and report generation facilities?	Useful
Q3: If you had access to this software, do you believe it would enhance the productivity of your research?	Somewhat
Q4: Would this reduce data management time?	Not At All
Q5: How important do you regard accuracy of image recognition and matching abilities of the software?	Very Important
Q6: How important do you regard speed efficiency within the software?	Important
Q7: How important do you regard ease-of-use and user-friendliness of the user interface?	Important
Q8: How important do you regard minimisation of manual data input (i.e. more automation)?	Not Important
Q9: Do you know of or use software, which has similar facilities to those previously mentioned?	Yes

Name: Mr Scott Taylor
Position: Director
Department: Cetacean Studies Institute
Country: Australia
Comments: *nil*

Q1: How valuable would software package that accurately identifies and matches cetacean specimens from collection of digital photographs be?	Very Valuable
Q2: How useful would this software be, if it was integrated with user-friendly data management and retrieval, statistical data analysis, and report generation facilities?	Very Useful
Q3: If you had access to this software, do you believe it would enhance the productivity of your research?	Somewhat

Q4: Would this reduce data management time?	Somewhat
Q5: How important do you regard accuracy of image recognition and matching abilities of the software?	Very Important
Q6: How important do you regard speed efficiency within the software?	Important
Q7: How important do you regard ease-of-use and user-friendliness of the user interface?	Important
Q8: How important do you regard minimisation of manual data input (i.e. more automation)?	Important
Q9: Do you know of or use software, which has similar facilities to those previously mentioned?	No

Name: Mr Mike Bossley
Position: Manager, Conservation & Education
Department: Conservation Research Department, Whale & Dolphin Conservation Society
Country: Australia
Comments: I hope you are able to develop the kind of software anticipated above! My understanding of FinScan and similar programs is that they still require a large amount of manual verification, making them of dubious value.

Q1: How valuable would software package that accurately identifies and matches cetacean specimens from collection of digital photographs be?	Very Valuable
Q2: How useful would this software be, if it was integrated with user-friendly data management and retrieval, statistical data analysis, and report generation facilities?	Very Useful
Q3: If you had access to this software, do you believe it would enhance the productivity of your research?	Considerably
Q4: Would this reduce data management time?	Somewhat
Q5: How important do you regard accuracy of image recognition and matching abilities of the software?	Very Important
Q6: How important do you regard speed efficiency within the software?	Important
Q7: How important do you regard ease-of-use and user-friendliness of the user interface?	Very Important
Q8: How important do you regard minimisation of manual data input (i.e. more automation)?	Very Important
Q9: Do you know of or use software, which has similar facilities to those previously mentioned?	No

Name: Zoe Squires
Position: Research Assistant
Department: Dolphin Research Institute
Country: Australia
Comments: Can you please send me a copy when you're done. Good Luck!

Q1: How valuable would software package that accurately identifies and matches cetacean specimens from collection of digital photographs be?	Very Valuable... Especially valuable if it can match individuals, not just species.
Q2: How useful would this software be, if it was integrated with user-friendly data management and retrieval, statistical data analysis, and report generation facilities?	Very Useful
Q3: If you had access to this software, do you believe it would enhance the productivity of your research?	Considerably
Q4: Would this reduce data management time?	Considerably
Q5: How important do you regard accuracy of image recognition and matching abilities of the software?	Very Important
Q6: How important do you regard speed efficiency within the software?	Important
Q7: How important do you regard ease-of-use and user-friendliness of the user interface?	Important... Probably only specialists would use it.
Q8: How important do you regard minimisation of manual data input (i.e. more automation)?	Important
Q9: Do you know of or use software, which has similar facilities to those previously mentioned?	No

Name: Mr Vic Cockcroft
Position: Director
Department: Centre for Dolphin Studies
Country: South Africa
Comments: An out of the box system will be difficult. Different species have different fins and descriptor, identifiable features. Some use nicks, others marks, others the fin shape. We've tried many methods to develop a system for the above, most work to a degree, but only for one species. I'd like to know your ideas, what you envisage doing.

Q1: How valuable would software package that accurately identifies and matches cetacean specimens from collection of digital photographs be?	Very Valuable
Q2: How useful would this software be, if it was integrated with user-friendly data management and retrieval, statistical data analysis, and report generation facilities?	Very Useful
Q3: If you had access to this software, do you believe it would enhance the productivity of your research?	Considerably
Q4: Would this reduce data management time?	Considerably
Q5: How important do you regard accuracy of image recognition and matching abilities of the software?	Very Important
Q6: How important do you regard speed efficiency within the software?	Important
Q7: How important do you regard ease-of-use and user-friendliness of the user interface?	Important

Q8: How important do you regard minimisation of manual data input (i.e. more automation)?	Not Important
Q9: Do you know of or use software, which has similar facilities to those previously mentioned?	No

Name: Stephanie Nowacek
Position: Lab Manager
Department: Sarasota Dolphin Research Program
Country: U.S.A.
Comments: *nil*

Q1: How valuable would software package that accurately identifies and matches cetacean specimens from collection of digital photographs be?	Very Valuable
Q2: How useful would this software be, if it was integrated with user-friendly data management and retrieval, statistical data analysis, and report generation facilities?	Useful
Q3: If you had access to this software, do you believe it would enhance the productivity of your research?	Somewhat
Q4: Would this reduce data management time?	Somewhat
Q5: How important do you regard accuracy of image recognition and matching abilities of the software?	Very Important
Q6: How important do you regard speed efficiency within the software?	Very Important
Q7: How important do you regard ease-of-use and user-friendliness of the user interface?	Very Important
Q8: How important do you regard minimisation of manual data input (i.e. more automation)?	Important
Q9: Do you know of or use software, which has similar facilities to those previously mentioned?	No

Name: Dr Dan Kerem
Position: President
Department: Israeli Marine Mammal Research & Assistance Center
Country: Israel
Comments: What would be useful for us is one which will utilize advanced analytical methods (pattern recognition, contour analysis etc) to match new photos with our own photo database/cataloge, that would save us time in deciding whether we recaptured an individual or photographed a new one. We already have an integrative and interactive database managing system (which includes sea sightings information, beaching information, autopsy procedures and results etc.), that allows statistical analysis. It took two students two years to develop. We do not have good software that would aid in photo-ID mark-recapture analysis, so anything that you may develop in that direction, would be very useful for us. Would certainly like to get a copy of your thesis.

Name: Mr Phil Coulthard
Position: Marine Biologist

Department: Dolphin Discovery Centre
Country: Australia
Comments: Great idea; however there are a few programs out there that provide a similar application. I have no idea what they are at present but a little research will provide the answers.

Q1: How valuable would software package that accurately identifies and matches cetacean specimens from collection of digital photographs be?	Very Valuable
Q2: How useful would this software be, if it was integrated with user-friendly data management and retrieval, statistical data analysis, and report generation facilities?	Very Useful
Q3: If you had access to this software, do you believe it would enhance the productivity of your research?	Considerably
Q4: Would this reduce data management time?	Considerably
Q5: How important do you regard accuracy of image recognition and matching abilities of the software?	Very Important
Q6: How important do you regard speed efficiency within the software?	Very Important
Q7: How important do you regard ease-of-use and user-friendliness of the user interface?	Very Important
Q8: How important do you regard minimisation of manual data input (i.e. more automation)?	Very Important
Q9: Do you know of or use software, which has similar facilities to those previously mentioned?	No

Name: Mrs Ewa Krzyszczyk
Position: Research Associate for the Shark Bay Research Foundation
Department: Department of Biology
Country: U.S.A.
Comments: Just wondering if you have heard of europhlukes which is currently being changed to euroflukes this is being managed by the European cetacean society and it recognises and manages dorsal pics and fluke pics, but currently still in progress but it does not do anything but sort through the nearest match for a dolphin/whale you are looking for. Also a suggestion is that as a lot of man hours have gone into putting pics into other programs the new program needs to be able to take pics already manually entered into other programs and put them into the new program without having to retrace the fins as having to retrace fins old and new will take forever!!!!

Q1: How valuable would software package that accurately identifies and matches cetacean specimens from collection of digital photographs be?	Very Valuable
Q2: How useful would this software be, if it was integrated with user-friendly data management and retrieval, statistical data analysis, and report generation facilities?	Very Useful
Q3: If you had access to this software, do you believe it would enhance the productivity of your research?	Considerably
Q4: Would this reduce data management time?	Somewhat

Q5: How important do you regard accuracy of image recognition and matching abilities of the software?	Very Important
Q6: How important do you regard speed efficiency within the software?	Very Important
Q7: How important do you regard ease-of-use and user-friendliness of the user interface?	Very Important
Q8: How important do you regard minimisation of manual data input (i.e. more automation)?	Very Important
Q9: Do you know of or use software, which has similar facilities to those previously mentioned?	Yes

Name: Guido Parra
Position: Postdoctoral Researcher
Department: School of Veterinary Science, University of Queensland
Country: Australia
Comments: The two programs that I know of are for identifying individuals from photographs of their dorsal fins or flukes. It would be good for you to get in contact with the developers of these programs, to see what can be improved and what needs further work.

Q1: How valuable would software package that accurately identifies and matches cetacean specimens from collection of digital photographs be?	Very Valuable
Q2: How useful would this software be, if it was integrated with user-friendly data management and retrieval, statistical data analysis, and report generation facilities?	Very Useful
Q3: If you had access to this software, do you believe it would enhance the productivity of your research?	Considerably
Q4: Would this reduce data management time?	Considerably
Q5: How important do you regard accuracy of image recognition and matching abilities of the software?	Very Important
Q6: How important do you regard speed efficiency within the software?	Very Important
Q7: How important do you regard ease-of-use and user-friendliness of the user interface?	Very Important
Q8: How important do you regard minimisation of manual data input (i.e. more automation)?	Very Important
Q9: Do you know of or use software, which has similar facilities to those previously mentioned?	Yes

Appendix B – Test Case Design & Process

The following test case design was implemented for the purpose of this study. This test case design is based on the *Requirements-based Testing* approach as outlined by Sommerville (2004). This approach is also supported by Pressman (2005) in his discussion on testing strategies. The following design provides a concise overview of the process taken in obtaining the test results used as a main part of this study's analysis. As defined in previous sections of this study, specific requirements have been identified for the tests on the prototype software. The requirements are the:

- Amount of User Input Required
- Type of User Input Required
- Total User Input Time
- Total Automatic Extraction Time
- Overall Accuracy Rating

Test cases will adopt the specifications outlined both by Sommerville (2004) and Pressman (2005). For this test case design, the specifications require the following data to be identified and recorded, in the sequence listed below:

1. Test Case Record ID
2. Start Time
3. Description
4. Input
5. Expected Output
6. Actual Output
7. Finish Time

Additional fields that must also be recorded in sub-sections of each test case scenario include the user input time, type of user input, automatic extraction time, and the overall accuracy rating. The following tables illustrate some of the test cases performed on each prototype design.

Test Cases for 1st Prototype Design

Note: start and finish times are approximate and longer than normal, due to recording the test-case scenarios.

ID	Start Time	Description	Input	Expected Output	Actual Output	Finish Time
1	14:32:26	Open an image file	JPEG image file of dolphin dorsal fin	Scale and display selected image file in viewable area	...as expected	14:32:51
2	14:33:15	Begin selecting the object in the image to extract (segment)	Click with mouse in main area of fin	Large portion or all of fin will be filled with selection colour	Part of fin is filled. Accuracy depends entirely on the tolerance level	14:33:25
3	14:33:30	Adjust the tolerance level and continue selecting the object to extract from the photograph	Click in areas of fin with mouse to complete selection	Entire fin will be filled with selection colour, ready for extraction process to begin	Most of fin filled/selected, some small parts inside fin still unselected though	14:34:12
4	14:34:25	Perform the extraction and edge detection	Select to extract selection and perform edge detection	Display extraction and edge-detection in real-time. Should produce an accurate result	...as expected, however accuracy is only about 90% for this test-case	14:34:38

Test Cases for 2nd Prototype Design

Note: start and finish times are approximate and longer than normal, due to recording the test-case scenarios.

ID	Start Time	Description	Input	Expected Output	Actual Output	Finish Time
1	14:40:09	Open an image file	JPEG image file of dolphin dorsal fin	Display selected image file in viewable area	...as expected	14:40:21
2	14:41:00	Select the outline of the object in the image to extract (segment)	Use alternate keyboard and mouse operations to draw an outline around fin	An outline accurately drawn around the edge of the dorsal fin	...as expected, 100% accuracy rating	14:42:00
3	14:42:12	Extract and save selected object to an image file	Filename and location to save to	Selected object is accurately extracted and saved to file	...as expected	14:42:25

Test Cases for 3rd Prototype Design

Note: start and finish times are approximate and longer than normal, due to recording the test-case scenarios.

ID	Start Time	Description	Input	Expected Output	Actual Output	Finish Time
1	14:44:25	Open an image file	JPEG image file of dolphin dorsal fin	Display selected image file in viewable area	...as expected	14:44:35
2	14:44:40	Use paint brush to roughly select area of fin for extraction	Mouse click and drag operations over fin	Full area of roughly selected fin is accurately extracted	Majority of roughly selected fin is extracted, not as accurate as expected	14:45:20
3	14:45:28	Crop extracted image to desired area and size	Mouse click and drag operations using cropping facility	Image is cropped to the user-defined area and size	...as expected	14:45:55

Test Cases for 4rd Prototype Design

Note: start and finish times are approximate and longer than normal, due to recording the test-case scenarios.

ID	Start Time	Description	Input	Expected Output	Actual Output	Finish Time
1	14:51:32	Open an image file	JPEG image file of dolphin dorsal fin	Display selected image file in viewable area	...as expected	14:51:40
2	14:51:42	Select to auto-detect and extract the dolphin dorsal fin	Click on Detect Dorsal Fin button	The fin is automatically identified and extracted	...as expected, accuracy about 90%	14:51:55
3	14:52:05	Open another image file for additional testing	JPEG image file of dolphin dorsal fin	Display selected image file in viewable area	...as expected	14:52:15
4	14:52:20	Select to auto-detect and extract the dolphin dorsal fin	Click on Detect Dorsal Fin button	The fin is automatically identified and extracted	Fin is detected, however, accuracy is not acceptable	14:52:22
5	14:52:24	Select to adjust the grey tolerance level for better accuracy	Use mouse to adjust the tolerance value	New tolerance value is initialised	...as expected	14:52:28
6	14:53:05	Select to auto-detect and extract the dorsal fin as before	Click on Detect Dorsal Fin button	The fin is automatically identified and extracted	...as expected, about an 85% accuracy; acceptable	14:53:08
7	14:53:15	Select to crop the extracted area	Click Crop button and use dynamic cropping box to select area of image to crop	Image is cropped to the user-defined area and size	...as expected	14:53:25

Appendix C – Survey Form

The following provides screenshots of the actual survey form used for this study. The survey was used to gather enough preliminary evidence to support the feasibility of this research. The following illustrates the survey form content:

Automated Photo-Identification and Analysis Computer
program for Marine Research in Cetaceans

SURVEY

In an effort to determine the viability of developing a software package that will provide an intelligent interface to assist and enhance the productivity of marine researchers in the study of cetaceans has necessitated this online survey. Your input is greatly appreciated. Survey results will be used to establish the requirements in the development of such software.

Again, thank you for taking the time to contribute.

(1) How valuable would a computer software system be, which accurately identifies and matches cetacean species from a collection of digitally stored photographs?	Not Valuable	Valuable	Very Valuable
(2) How useful would the software described above be, if it were integrated into a software package providing user-friendly data management and retrieval, statistical data analysis, and report generation facilities?	Not Useful	Useful	Very Useful
(3) If you had access to the integrated software package described above, do you believe it would enhance the productivity of your research?	Not at all	Somewhat	Considerably
(4) Would this type of software package save your data management time, allowing more time for field work?	Not at all	Somewhat	Considerably
(5) How important do you regard accuracy of the image recognition and matching abilities of the software?	Not Important	Important	Very Important
(6) How important do you regard speed efficiency within the software?	Not Important	Important	Very Important
(7) How important do you regard ease-of-use and user-friendliness of the user interface?	Not Important	Important	Very Important
(8) How important do you regard the minimisation of manual data input when using the software? (e.g. automated inputting of standard data fields)	Not Important	Important	Very Important
(9) Do you know of or use software, which has similar facilities to those mentioned above?	Yes	No	

Please provide any additional comments/interests/ideas/suggestions here:

The following section asks for general information about who you are...

Your name:

Your position:

Department/Business Postal Address:

E-mail address:

Name of your research department/centre:

Country:

Submit Survey

Depending on the answer for question 9, the survey form may expand to show as follows:

Automated Photo-Identification and Analysis Computer program for Marine Research in Cetaceans

SURVEY

In an effort to determine the viability of developing a software package that will provide an intelligent interface to assist and enhance the productivity of marine researchers in the study of cetaceans has necessitated this online survey. Your input is greatly appreciated. Survey results will be used to establish the requirements in the development of such software.

Again, thank you for taking the time to contribute.

(1) How valuable would a computer software system be, which accurately identifies and matches cetacean species from a collection of digitally stored photographs?	○ Not Valuable	○ Valuable	○ Very Valuable
(2) How useful would the software described above be, if it were integrated into a software package providing user-friendly data management and retrieval, statistical data analysis, and report generation facilities?	○ Not Useful	○ Useful	○ Very Useful
(3) If you had access to the integrated software package described above, do you believe it would enhance the productivity of your research?	○ Not at all	○ Somewhat	○ Considerably
(4) Would this type of software package save your data management time, allowing more time for field work?	○ Not at all	○ Somewhat	○ Considerably
(5) How important do you regard accuracy of the image recognition and matching abilities of the software?	○ Not Important	○ Important	○ Very Important
(6) How important do you regard speed efficiency within the software?	○ Not Important	○ Important	○ Very Important
(7) How important do you regard ease-of-use and user-friendliness of the user interface?	○ Not Important	○ Important	○ Very Important
(8) How important do you regard the minimisation of manual data input when using the software? (e.g. automated inputting of standard data fields)	○ Not Important	○ Important	○ Very Important
(9) Do you know of or use software, which has similar facilities to those mentioned above?	○ Yes ○ No		

Are you currently using this software?	○ Yes ○ No		
How do you rate its user interface in terms of ease-of-use?	○ Poor	○ Good	○ Very Good
Does the program have an image recognition component?	○ Yes ○ No		
If so, how do you rate its image recognition facilities in terms of ease-of-use, speed and accuracy?	○ Poor	○ Good	○ Very Good
How do you rate its efficiency in terms of time required to manually enter, manage, retrieve and analyse data?	○ Poor	○ Good	○ Very Good
How do you rate its flexibility and generic properties, when managing databases of varying research fields?	○ Poor	○ Good	○ Very Good
What is the name of the software package?			
Is it commercially available?	○ Yes ○ No		
Has it been custom developed for your research department?	○ Yes ○ No		

Please provide any additional comments/interests/ideas/suggestions here:

The following section asks for general information about who you are...

Your name:

Your position:

Department/Business Postal Address:

E-mail address:

Name of your research department/centre:

Country:

Submit Survey

Appendix D – Included CD Media

Attached with this paper is a compact disc (CD), containing electronic video recordings that demonstrate the processes taken to test the prototype software designs (Appendix A). These recordings are not the original tests performed on the designs during the analysis stage of this investigation. However, the general operations of the prototype software can be depicted in more detail by viewing them. In addition, these recordings provide evidence supporting the existence and operability of the prototype software designs discussed in this paper. To view the video files, you will need a CD-Player supporting this type of compact disc, along with video playing software, such as Microsoft® Windows® Media Player.