PHOTO-IDENTIFICATION SOFTWARE FOR BOWHEAD WHALE IMAGES

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ABSTRACT

A computer program has been developed for identification of individual bowhead whales in aerial photographs. The program enables the user to create a collection of images and to compare an image to the collection. The collection is ranked by the program based on similarity to the query image, facilitating identification of the individual in the image. The program has been tested by the developer (GRH) with 20 images and it appears to compute its matching functions correctly. Eleven successive versions of the program were provided to LGL Limited, who tested the program with a collection of 78 images and have provided reports on bugs in the system and feature requests to the developer. All known bugs have been fixed and many features have been added to make the program perform better. Additional modifications to the program are likely to improve matching performance and will be identified when larger numbers of images have been processed through the program.

KEY WORDS: BOWHEAD WHALE, PHOTO-ID, MARK-RECAPTURE, ARCTIC, COMPUTER-MATCHING

INTRODUCTION

The photographic database of the Bering-Chukchi-Beaufort Seas (BCBS) population of bowhead whales (*Balaena mysticetus*) contains almost 18,000 images collected from the late 1970s to 2007. More than half of the 14,682 images that have been classified according to image quality are of adequate quality to determine if the whales are marked and could be recognized if they were photographed in the future. All of the images in the database, but particularly the high quality images, have provided useful information on life-history parameters including calving intervals (Miller *et al*., 1992; Rugh *et al*., 1992a), growth rates (Koski *et al*., 1992, 1993), population structure (Davis *et al*., 1983; Koski *et al*., 1993, 2006, 2007; Angliss *et al*., 1995), population size (Rugh, 1990; da Silva *et al*., 2000; Schweder, 2003; Schweder and Sadykova, 2007; Koski *et al*., 2008) and survival rates (Whitcher *et al*., 1996; Zeh *et al*., 2002). These data continue to be used in various on-going studies to further describe various parameters of bowhead whale life history and population dynamics (Rugh *et al*., 2007).

The size of the bowhead photographic database has increased to the point where collection of new photographs results in a relatively high probability of re-sighting a previously photographed marked whale. The proportion of the population that has been photographed has increased, and consequently, the likelihood of photographing a whale that has been photographed during previous studies has increased dramatically. Thus, new photographs at this time provide much more information both on individual whales and the population than the same number of photographs did during the early years of bowhead whale photography studies (Schweder and Sadykova, MS). However, as the number of marked whales in the collection has increased, the time required to match each new photograph to earlier marked whales has also increased. To assist with the matching of the rapidly-growing number of photographs in the BCBS photographic collection, we have developed a computer-assisted matching program. This paper describes the development and current capabilities of the program and discusses future testing and development that will improve the efficiency of the program.

METHODS

Programming

All programming was done using the Matlab (The Mathworks, Inc., Natick, MA) development system. This is the same system that has been used for earlier matching programs for sea otters and gray whales and has replaced the Visual Basic/C++ languages used for dolphin matching (Hillman *et al*., 2003; Markowitz *et al*., 2003). The program was written using Matlab's scripting language and graphical user interface (GUI) developer. The resulting files can be provided to any potential user who has a current Matlab installation. They can also be compiled by the programmer to produce MS Windows executable files, which run on any Windows XP or Vista machine. A Matlab runtime file, which the programmer is permitted by Matlab to distribute to end-users, must also be installed along with the executable file. For this project, the Matlab runtime and the executable files were sent to LGL Limited (LGL) and the National Marine Mammal Laboratory (NMML), and personnel there successfully installed and ran the program.

Entering images into the program

Bowhead whale images (TIF or JPG files) are opened in the matching program; other common file formats could be accommodated. When an image is opened, the program automatically creates specific subfolders into which the program will insert the data about the whale's marking pattern that will be computed from the user's input. The information for each image in a folder will be added to these subfolders by the program as the images are entered.

Once an image is open, the user selects "Geometric Transform" from a menu. The image appears in a new window next to a provided "standard" image, which is simply a whale image of excellent quality used as a reference image to help map features on the new image to be entered into the system. The user clicks on two points in the new image, such as the tip of the rostrum and the end of the fluke, and on the corresponding two points in the standard image. The program scales, rotates, and translates the new image so that all images have the same rotation and scaling. The normalization parameters are saved and are applied to that image each time it is read by the program.

Some images were not sufficiently normalized by this procedure because the whale was flexed or twisted in the image. Therefore, an "Un-twist" option was added to the image capture procedure. The user selects "Un-twist" from the menu and then clicks on the tip of the rostrum, a series of at least four points along the anatomic midline and the base of the fluke. The program performs a nonlinear distortion of the image that causes the designated points to fall on the line between the rostrum and the fluke, with interpolation of all pixels between the selected points. When the control points have been selected, the image is rotated such that the first and last points fall on the same horizontal row. A spline is then drawn through the intermediate points, with a spline point computed at each pixel column. Each column is then revolved along its vertical length so that the spline points all fall on the horizontal between the snout and the tail. The entire image is then rotated back to its original orientation. This process is fairly slow (at least several seconds), so it should not be used unless there is enough curvature or twisting to disrupt the location of identifying marks. This process is automatic once the six or more control points have been selected.

The user then selects the markings on the whale that are to be used for identification. First, a mouse click selects each mark. If the mark is a small dot, no further action is needed. If it is a large mark or has a distinctive shape, the user may click on a series of points around the mark to outline it, and the data about its size and shape are stored for use in matching. Users may review an image and add, edit, or delete stored marks without re-doing the entire mark selection for that image. This feature allows updating of mark information for a whale from second and subsequent photos of the same whale. This ensures that the mapped image is an accurate representation of a whale and permits us to incorporate information from multiple images of a whale into a single image for matching.

Because some regions of a whale are not clearly visible on some photographs due to wash, glare, etc., the user may designate all (the program default) or part of each image as a region of interest (ROI) for matching. This is done by clicking around the ROI to create a polygon that includes only the ROI. If such a region is designated, the program will disregard marks outside of the ROI in other images during the matching process. If no ROI is selected, the entire image is treated as the ROI.

The scaling and orientation, un-twisting, ROI, and locations and descriptions of the distinguishing marks are automatically stored in the subfolders, and are recalled by the program as needed.

To enter, normalize, and mark an image takes 3-7 minutes, depending on the quality of the image and how many spots must be marked or outlined. When this process is complete, the user selects "Add to Excel File." This adds the file path and name of the new image to a list maintained in a MS Excel file; this file stores the names of all files in the catalogue and the identity of the whale in the image. When the image is first added to the file, the program adds the identifier "0000" as its ID, later to be changed by the user when the image is identified either as a new individual or as a match to a previous image. The files listed in the Excel document are the ones to which each new image is matched.

Matching Images

The user selects any image for identification. In order to be matched to the rest of the collection, the image must have been previously normalized and its spots marked. If the normalization and spot marking procedures have not been completed for the selected image, a notice reminds the user to complete them.

Since, the size, orientation and shape of scars are sometimes distinctive, the user is given an option to indicate the shape of any mark rather than indicating only its location. For example, this option would be used if a whale had a distinctively-shaped mark so that all whales with a similar-shaped mark at the same location would be ranked higher on the list of potential matches than they might be without selection of this option (Fig. 1). The parameters measured for each mark are: location, area (number of pixels), eccentricity (a numerical indication of the shape of the spot, ranging from 0 (round) to 1 (straight line)), orientation (angle in degrees from horizontal of the major axis), length (the major axis, measured in pixels, of an ellipse that approximates the mark) and perimeter (number of pixels). These parameters are calculated automatically once the user has outlined a spot with the mouse. If a spot's location is marked, but the spot is not outlined, the system assumes that the spot is a small circle. When marks are matched, the difference between them is the Euclidean distance in the data seven-dimensional space of these parameters (x position, y position, area, eccentricity, eccentricity×orientation [i.e., if it is round its orientation is not relevant], length and perimeter). Each of the parameters is weighted by the default value unless other values are selected. The default weight is 1 for all parameters except eccentricity, for which the weight is 10 (because its native value is limited to 0 to 1) and 0.01 for area. The user can set the weighting value to zero to force a parameter not to contribute to the matching process, or set the weight to any higher number to have a characteristic of the mark weighted more heavily. The program saves the new weights in a file called "wtfile.mat." The capability for the user to vary the weights is a part of the development process, as experience will tell us which of the computed parameters are most helpful for identification, and therefore should be weighted more heavily, and which, if any, should be counted less heavily or not at all. It is also possible that the user may wish to adjust the weights according to the properties of the query image

Any two images may be compared by reading one as "Image 1" and the other as "Image 2." A "Compare two images" button measures and displays the difference between the two images. This quick matching function is useful during testing of the program and for new users to learn how changing options affects the matching process.

In the usual operation of the program, the user does not open an "Image 2", but instead, clicks a "Compare to List" button. In this case, all of the images listed in the Excel file are matched to Image 1. The program measures the dissimilarity between the query image and each listed image, and displays a list of images ordered from the lowest to the highest dissimilarity value. As a result, the images that are most similar to the query image are at the top of the list. It then displays a window with the sorted list and the dissimilarity value. The program also displays the top six images on the list along with file names and ID's (Fig. 2). Each of these six images has a button that allows the image to be displayed in a separate large window, with its selected marks shown. If the user sees a match among those six images, he enters the ID of the query image in a provided text box. If a match is not seen, the user may view the next six. The user can scroll through the catalogue of images in either direction, displaying them six at a time, until a match is found, or the user is convinced that there is no match. Either a pre-existing or a new ID may be entered, and it is recorded in the Excel file instead of the default "0000".

The presence or absence of a match is confirmed by a trained observer with assistance of the program. The goal of the program is to reduce the number of images that must be reviewed. If the program worked perfectly, its first suggestion would always be a match, if one existed. This ideal goal cannot always be achieved because some matching errors are inevitable, some images are unclear and some whales either lack distinctive markings or have markings resembling those on other individuals. Nevertheless, if a correct match occurs at or near the top of the list, the amount of labour previously needed to search for matches will be reduced..

Comparison to earlier programs

The overall design of the program is modelled on previous photo-ID programs that were developed for other species such as dolphins, sea otters, and gray whales (Hillman *et al.*, 2003; Markowitz *et al.*, 2003). The bowhead program code is entirely new, with many features that are specific to the bowhead whale application.

The processes of file access, Excel file access, image display and mouse-use take advantage of Matlab functions. The scale-rotation-translation normalization process uses Matlab's linear conformal transformation. However, the un-twisting function is a new algorithm. This process is fairly slow (at least several seconds), so it should not be used unless there is enough curvature or twisting to disrupt the location of identifying marks.

Matching function

The matching function works as follows, with the process repeated as the query image is matched in turn to each image in the collection:

- The program recalls the locations and shape properties of the two images (A and B) being matched.

- If A or B has a designated ROI, the marks in the other image are tested to determine whether they fall within this region. Any marks that are outside the other image's valid region are temporarily discarded.
- The Euclidian distance is determined between each point in A and B in a 7-dimensional space comprised of the X distance, Y distance, mark area, mark eccentricity (a scale from 0 to 1 indicating shape from a circle to a line), angular orientation of the mark, length of the major axis of the mark and perimeter of the mark, each parameter weighted by its weighting value. The closest points are determined. If the images have unequal numbers of marks, the smaller number is used (e.g. if A has 3 and B has 5 marks, the closest 3 pairs of points are found)
- Using a linear translation function and Matlab's optimization algorithm, the relative position of the two images is adjusted to minimize the distances between the corresponding closest-fit points.

The difference values between the query and all other images are accumulated and sorted, establishing the order in which images are presented for inspection.

A second matching algorithm was also implemented after discussion with an engineering colleague, Dr. Hemant Tagare at Yale University. Rather than the successive-approximations optimization of the point locations, the algorithm uses an analytical minimization of the summed distance, with a specified number of iterations. The advantage of this method is that it can weight the distances in such a way that the matching value is weighted more heavily by points that fit more closely than those that are distant matches. The result of this weighting is to reduce the influence of outlying marks that might be due to errors or artefacts. The user of the program can select either of the two matching algorithms; experience will tell whether one is actually more effective than the other.

DISCUSSION

A computer-assisted matching program has been developed using 20 bowhead whale images and has been tested with a set of 78 images. These relatively small collections were used to develop the program and determine whether the programming was free of errors, but we have not used the program with larger numbers of images. A much larger data set is now being prepared for testing. The program runs without bugs or crashes, but does not yet reliably trap user errors or other unexpected input. The program can be improved by adding features such as internal help files and additional user error trapping. The latest version of the program was provided to LGL and NMML on 23 April 2008.

A closer examination of weights is needed to determine relative influence of distance, area, etc. of marks on the similarity of a matched pair of images; it is still uncertain what values to assign to these weights in order to provide the most accurate matching. In order to facilitate the matching process, the program also needs to allow more flexibility in organizing data files. Most importantly, the program needs to be tested using a large collection of images that have already been matched to determine how far down the list of suggested matches a correct match may occur. Additional features that may improve the reliability of the matching process have been requested by the testers at LGL and NMML. Throughout the development process there has been frequent and effective communication between the programmer and the testing groups, and the result is a working draft of a program that may be extremely helpful for matching bowhead whale images.

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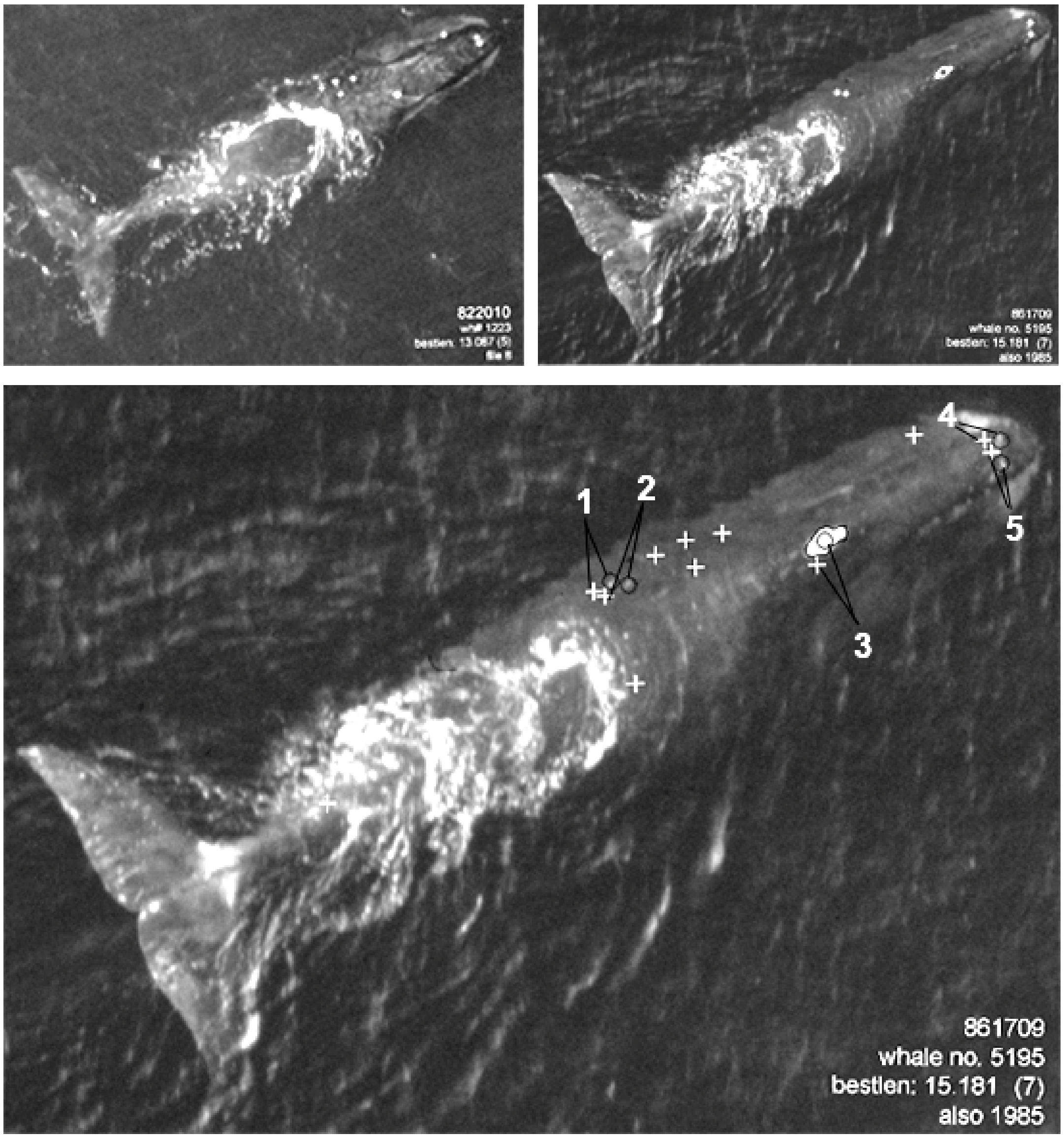

Fig. 1. The value of using the “Weight Attributes” function is illustrated in the program ranking of the above images as matches. The top left panel shows whale 1 with spots marked. The top right panel shows whale 2 with spots marked. The bottom panel shows marks of both whales 1 (plus signs) and whale 2 (circles) superimposed on whale 2. These two whales are not a match, but without using the Weight Attributes function the program recognizes these 2 whales as a good match because 5 marked spots match very well. If however, the Weight Attributes are adjusted to account for the large distinct mark #3, the match probability is decreased and more accurate matching rank is achieved.

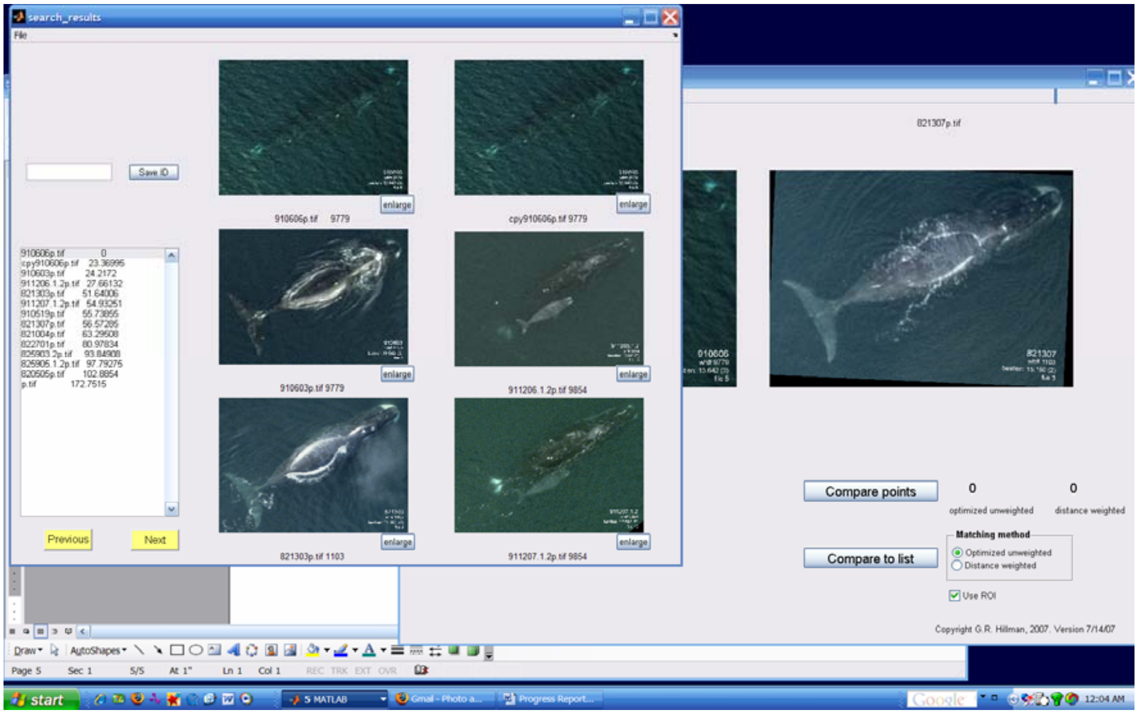

Fig. 2. Search results screen (front) and main screen (behind).